A CHARACTERIZATION OF SOILBORNE FUNGI ASSOCIATED WITH PEANUT (*ARACHIS HYPOGAEA* L.) IN FLORIDA

By

ROBERT CHESTER KEMERAIT, JR.

A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

2000

To
Janet and Robert Kemerait

ACKNOWLEDGEMENTS

This project has been a challenge from its inception. I am indebted to many people for their support, advice, and encouragement in my growth as a plant pathologist and in the completion of this study. The success of this work is a reflection of their commitment to me; any faults in this work are my own.

Dr. Tom Kucharek has been a mentor since I began these graduate studies and has provided me with many opportunities unavailable to other students. He has given me the chance to work with growers in the field and then allowed me the latitude to pursue this research in directions that were rewarding and exciting to me. His generosity of time and the financial resources have been unfailing. He has helped to focus my passion for applied plant pathology and extension work and prepared me for a rewarding career of service to the grower.

I would like to thank Dr. George Agrios for his support throughout my stay in the Plant Pathology Department. Since our first meeting in February of 1994, he has put the utmost faith in my potential to succeed as a plant pathologist and provided support to me during much of my time in the department.

I am indebted to Dr. Lance Peterson and Dow Agrosciences for their generous financial support during the first three years of my graduate program. Without this early support, I may never have been able to begin my program with Dr. Kucharek.

I appreciate the contributions of the members of my advisory committee, Dr. Richard Berger, Dr. David Mitchell, Dr. Lance Peterson, Dr. Fred Shokes, and Dr. Ben Whitty to the completion of this program. They have provided guidance, suggestions, critiques, and encouragement throughout the many struggles of this project. I am especially grateful for the care that they spent in the editing and review of my dissertation.

I am very appreciative of the assistance, mentoring, advice, and encouragement given to me by Dr. Jim Kimbrough, Dr. Dan Purcifull, and Dr. Gerald Benny. Their help was invaluable and their kindness will not be forgotten.

I am fortunate to have been able to work in Dr. Kucharek's lab with Dr. Kenny Seebold, Mr. Ron Hoover, Mr. Charles Semer, Ms. Misty Nielsen, Mr. Anthony Dyess, and Mr. Mike Mahovic. They all contributed expertise and countless hours of time and effort for my sake. Mr. Ron Hoover built the sterilization boxes that I used so often during this study and Mr. Chuck Semer's experience with general plant pathology allowed me to add new and important facets to my research.

I appreciate the help of the county extension agents and the growers who so generously shared their time, knowledge, and resources with me during this research. This project could not have occurred without their cooperation. In Santa Rosa County, I owe gratitude and thanks to Mr. John Atkins, Mr. Greg Kimmons, Mrs. Janice Simmons, Mr. Keith Roland, Mr. Millard Holley, and Mr. B. D. Hendricks. In Jackson County I owe many thanks to Mr. Ed Jowers, Mr. John Stone, Mr. Ted Baxter, and Mr. Chuck Dickson. In Suwannee County, I

appreciate the help of Mr. Bob Tervola, Mr. Eddie Roberts, Mr. Robert Barnett, Mr. Bob Barnett, Mr. Kenneth Hall of Suwannee Farms, and Mr. Jimmy Daniels. In Columbia County, I appreciate the help of Mr. Bill Thomas and Mr. Lamar Mosely. In Levy County, I am indebted to Mr. Anthony Drew, Mr. Duane Fugate, Mr. Gene Fugate, Mr. Jeff Fugate, Mr. Steve Fugate, and Mr. Freddie Bell.

I appreciate the generous help provided to me by the faculty and staff from other departments at the University of Florida and from the various research facilities around the state. Mr. Jay Harrison from IFAS Statistics spent many hours helping me with statistics and introduced me to correspondence analysis. His patience was a blessing. Mr. Jim Bartos at the IFAS Soils Lab spent was helpful in the processing of soil samples. From the Department of Entomology and Nematology, I was assisted by Dr. Don Dickson, Mr. Tom Hewlett, Mr. Reggie Wilcox, and Mr. Frank Woods. At the Green Acres Agronomy Farm near Gainesville, I received generous help and support from Mr. Harry Wood. At the North Florida Research and Education Center in Quincy, I received tremendous support from Dr. Dan Rhodes, Mr. Don Berger, Mr. John Allen Smith, Mr. Ray Jordan, Mr. Claude Butler, and Mr. Leroy Marshall, and Mr. Ray Bass.

I am indebted to Mr. Lucious Mitchell, Mr. Gene Crawford, Ms. Gail Harris, Ms. Lauretta Rhames, Ms. Karen Owens, Ms. Polly Teale, and Ms. Patti Rayside for their assistance during the past five years.

My experience in the Plant Pathology Department at the University of Florida has been greatly enhanced by the many friends that I have made among the students. I am especially grateful for the assistance given to me by Dr. Erin

Rosskopf, Dr. Kenny Seebold, Dr. Carlos Forcellini, Dr. Dauri Tessman, Dr. Daniela Lopes, and Dr. Bob Harveson. They inspired me to pursue my research with dedication and perseverance.

I will always be indebted to Janet and Robert Kemerait for the opportunities and encouragement that they provided. Any success that I attain would not have been possible without them. They knew I could even when I didn't.

Finally, I am grateful for the support, trust, and faith that my wife, Pam, has put in me. My research has been continually demanding and has required much attention and travel away from home. Her support has never wavered and has inspired me to attain goals that I otherwise might not have sought.

TABLE OF CONTENTS

page

ACKNOWLEDGMENTS iii

LIST OF TABLES ix

LIST OF FIGURES xi

ABSTRACT xviii

CHAPTERS

1 INTRODUCTION 1

2 LITERATURE REVIEW 5

Arachis hypogaea L. 5
Origin of the Peanut 7
Taxonomy 7
The Peanut Plant 9
Peanut Production Practices in the United States 13
Soilborne Fungi 19
Inventories of Soilborne Fungi 22
Complexes of Soilborne Fungi 25
Environmental Influences on Soilborne Diseases 27
Cultivation Practices and Rotation in Soilborne Disease in Peanut 29
Use of Fungicides in the Control of Soilborne Disease in Peanut 30
Influence of Crop Development on Fungal Infection 31

3 SOILBORNE FUNGI ISOLATED FROM PEANUT PLANTS 37

Introduction 37
Materials and Methods 39
Results 59
Discussion 80
Conclusion 91

4 VARIABLES RELATED TO INCIDENCE OF SOILBORNE FUNGI.....92
Introduction 92
Materials and Methods 93
Results 101
Discussion 134
Conclusions.....151

5 SOILBORNE FUNGI AND THREE CULTIVARS OF PEANUT 153

Introduction 153
Materials and Methods 156
Results 164
Discussion 202
Conclusions.....215

6 FUNGICIDES AND THE INCIDENCE OF SOILBORNE FUNGI 217

Introduction 205
Materials and Methods 220
Results 225
Discussion 261
Conclusions.....273

7 INFLUENCE OF FOLIAR DISEASE ON SOILBORNE FUNGI 276

Introduction 276
Materials and Methods 278
Results 283
Discussion 305
Conclusions.....311

8 SUMMARY 313

REFERENCES 321

BIOGRAPHICAL SKETCH 338

LIST OF TABLES

Table — page

Table 3-1. Characteristics and cultural information collected from fields of peanut (*Arachis hypogaea* L.) in Florida in 1995 42
Table 3-2. Characteristics and cultural information collected from fields of peanut (*Arachis hypogaea* L.) in Florida in 1996 43
Table 3-3. Yields and fungicide information for commercial fields of peanut (*Arachis hypogaea* L.) in Florida in 1995 and 1996 44
Table 3-4. Number of plants evaluated from each site during sampling phase of peanut fungal survey 47
Table 3-5. Growth stages of peanut 48
Table 3-6. Numeric scheme to evaluate peanut plant health at time of processing 49
Table 3-7. Fungal isolates used in inoculation studies 53
Table 3-8. Incidence of fungi during peanut seedling and vegetative stages 63
Table 3-9. Abundance of soilborne fungi isolated from commercial and research peanut fields in Florida over an entire season 65
Table 3-10. Percentage of fields from which fungi were isolated based upon five regions in Florida 68
Table 3-11. Relative pathogenicity of fungal isolates inoculated into five-week-old peanut plants 71
Table 3-12. Pathogenicity of selected fungal isolates inoculated into Florunner peanut at five different ages and growth stages 73
Table 3-13. Pathogenicity of selected genera of fungi 25 days after inoculation of 14-day Florunner peanut seedlings at three different temperatures 75
Table 3-14. Competitive interactions between pathogenic isolates and selected non-pathogenic antagonists 77
Table 4-1. Range of crop ages and peanut growth stages for sequential sampling dates during 1995 and 1996 99
Table 4-2. Pearson's correlation coefficients of incidences of selected soilborne fungi from all commercial fields that were significant and ≥0.1 or ≤ -0.1 in the combined 1995 and 1996 seasons 103
Table 4-3. Pearson's correlation coefficients for incidence of selected soilborne fungi and field factors that were significant and ≥ 0.1 0.1 or ≤ -0.1 in both 1995 and 1996 104

Table 4-4. Main effects and interactions of sampling trip and plant part on recovery of eight soilborne fungal pathogens of peanut from commercial fields in Florida duriing 1995 and 1996 109
Table 4-5 Mean incidences of specific soilborne fungi as related to the year and time of season when plants were sampled and part of the plant from which the fungus was isolated..... 111
Table 5-1. Sampling information from a cultivar trial at the North Florida Research and Education Center, at Quincy..... 165
Table 5-2. Yield and disease severity among three cultivars of peanut grown at the North Florida Research and Education Center, Quincy during 1998 and 1999..... 166
Table 6-1. Sampling information from fungicide trials on peanut, Santa Rosa County, Florida..... 226
Table 6-2. Yield and disease severity during 1998 and 1999 associated with four fungicide programs on peanut in Santa Rosa County, Florida 227
Table 7-1. Sampling information from a leaf spot trial for peanut, Suwannee County, Florida in 1998..... 280

LIST OF FIGURES

Figure page

Figure 3-1. Counties in Florida where peanut plants were sampled during 1995 and 1996....40
Figure 3-2. Surface sterilization box....50
Figure 3-3. Interactions between fungi on acidified potato dextrose agar....58
Figure 3-4. Distribution of fungal genera by phylum and form-phylum (Deuteromycota) that were isolated during 1995 and 1996 from the roots, hypocotyls, pods, and pegs of peanut grown in Florida....61
Figure 4-1. Simple correspondence analysis from 1995 to establish the relationship between the time of sampling and the incidence of specific fungi isolated from peanut grown in 15 different commercial fields....121
Figure 4-2. Simple correspondence analysis from 1996 to establish the relationship between the time of sampling and the incidence of specific isolated from peanut grown in nine different commercial fields....123
Figure 4-3. Simple correspondence analysis from 1995 to establish the relationship between the parts of the plant and the incidence of specific fungi isolated from 15 commercial fields....126
Figure 4-4. Simple correspondence analysis from 1996 to establish the relationship between the parts of the plant and the incidence of specific fungi isolated from nine commercial fields....128
Figure 4-5. Simple correspondence analysis from 1995 to establish the relationship between the health rating given to each sampled plant and the incidence of specific fungi isolated from 15 commercial fields....131
Figure 4-6. Simple correspondence analysis from 1996 to establish the relationship between the health rating given to each sampled plant and the incidence of specific fungi isolated from nine commercial fields....133
Figure 5-1. Development of the foliar canopy among three cultivars of peanut at the North Florida Research and Education Center in 1998 (A) and 1999 (B)....168
Figure 5-2. Changes in temperature of the canopy (A) and soil (B)associated with three cultivars of peanut at the North Florida Research and Education Center, Quincy, Florida during 1999....169
Figure 5-3. The changes in % relative humidity within monitoring stations placed in the developing canopies of three cultivars of peanut at the North Florida Research and Education Center, Quincy, Florida....170

Figure 5-4. Development of foliar canopy at the North Florida Research and Education Center during June-September 1999 171
Figure 5-5. Simple correspondence analysis from 1998 to establish the relationship between the time of sampling and the incidence of specific fungi isolated from three different cultivars of peanut 174
Figure 5-6. Simple correspondence analysis from 1999 to establish the relationship between the time of sampling and the incidence of specific fungi isolated from three different cultivars of peanuts.....176
Figure 5-7. Simple correspondence analysis from 1998 to establish the relationship between the parts of the plant and the incidence of specific fungi isolated from three different cultivars of peanut 179
Figure 5-8. Simple correspondence analysis from 1999 to establish the relationship between the parts of the plant and the incidence of specific fungi isolated from three different cultivars of peanut 181
Figure 5-9. Simple correspondence analysis from 1998 to establish the relationship between the health rating given to each sampled plant and the incidence of specific fungi isolated from three different cultivars of peanut.....184
Figure 5-10. Simple correspondence analysis from 1999 to establish the relationship between the health rating given to each sampled plant and the incidence of specific fungi isolated from three different cultivars of peanut.....186
Figure 5-11. Incidence of *Aspergillus flavus* measured as the proportion of infected plants that were sampled from three cultivars of peanut planted at the North Florida Research and Education Center, Quincy, in 1998 (A) and 1999 (B).....188
Figure 5-12. Incidence of *Aspergillus niger* measured as the proportion of infected plants that were sampled from three cultivars of peanut planted at the North Florida Research and Education Center, Quincy, in 1998 (A) and 1999 (B).....189
Figure 5-13. Incidence of *Cylindrocladium parasiticum* measured as the proportion of infected plants that were sampled from three cultivars of peanut planted at the North Florida Research and Education Center, Quincy, in 1998 (A) and 1999 (B).....190
Figure 5-14. Incidence of *Fusarium* spp. measured as the proportion of infected plants that were sampled from three cultivars of peanut planted at the North Florida Research and Education Center, Quincy, in 1998 (A) and 1999 (B).....191
Figure 5-15. Incidence of *Lasiodiplodia theobromae* measured as the proportion of infected plants that were sampled from three cultivars of peanut planted at the North Florida Research and Education Center, Quincy, in 1998 (A) and 1999 (B).....192
Figure 5-16. Incidence of *Macrophomina phaseolina* measured as the proportion of infected plants that were sampled from three cultivars of peanut planted at the North Florida Research and Education Center, Quincy, in 1998 (A) and 1999 (B).....193

Figure 5-17. Incidence of *Neocosmospora vasinfecta* measured as the proportion of infected plants that were sampled from three cultivars of peanut planted at the North Florida Research and Education Center, Quincy, in 1998 (A) and 1999 (B).....194
Figure 5-18. Incidence of *Phomopsis* sp. measured as the proportion of infected plants that were sampled from three cultivars of peanut planted at the North Florida Research and Education Center, Quincy, in 1998 (A) and 1999 (B).....195
Figure 5-19. Incidence of *Pythium* spp. measured as the proportion of infected plants that were sampled from three cultivars of peanut planted at the North Florida Research and Education Center, Quincy, in 1998 (A) and 1999 (B).....196
Figure 5-20. Incidence of *Rhizoctonia solani* measured as the proportion of infected plants that were sampled from three cultivars of peanut planted at the North Florida Research and Education Center, Quincy, in 1998 (A) and 1999 (B).....197
Figure 5-21. Incidence of *Rhizopus* spp. measured as the proportion of infected plants that were sampled from three cultivars of peanut planted at the North Florida Research and Education Center, Quincy, in 1998 (A) and 1999 (B).....198
Figure 5-22. Incidence of *Sclerotium rolfsii* measured as the proportion of infected plants that were sampled from three cultivars of peanut planted at the North Florida Research and Education Center, Quincy, in 1998 (A) and 1999 (B).....199
Figure 5-23. Incidence of *Trichoderma* spp. measured as the proportion of infected plants that were sampled from three cultivars of peanut planted at the North Florida Research and Education Center, Quincy, in 1998 (A) and 1999 (B).....200
Figure 5-24. Incidence of *Zygorhinchus* sp. measured as the proportion of infected plants that were sampled from three cultivars of peanut planted at the North Florida Research and Education Center, Quincy, in 1998 (A) and 1999 (B).....201
Figure 6-1. Development of the foliar canopies associated with four different fungicide programs in two commercial fields in Santa Rosa County, Florida in 1998 (A) and 1999 (B).....229
Figure 6-2. Changes in the canopy (A) and soil (B) temperature associated with two fungicide programs in a commercial field in Santa Rosa County during 1999 230
Figure 6-3. The changes in % relative humidity within monitoring stations placed in the developing canopies of peanut that received different fungicide programs in a commercial field in Santa Rosa County.....231
Figure 6-4. Simple correspondence analysis from 1998 to establish the relationship between the time of sampling and the incidence of specific fungi isolated from four fungicide treatments 234

Figure 6-5. Simple correspondence analysis from 1999 to establish the relationship between the time of sampling and the incidence of specific fungi isolated from four fungicide treatments 236
Figure 6-6. Simple correspondence analysis from 1998 to establish the relationship between the parts of the plant and the incidence of specific fungi isolated from four fungicide treatments 239
Figure 6-7. Simple correspondence analysis from 1999 to establish the relationship between the parts of the plant and the incidence of specific fungi isolated from four fungicide treatments 241
Figure 6-8. Simple correspondence analysis from 1998 to establish the relationship between the health rating given to each sampled plant and the incidence of specific fungi isolated from four fungicide treatments 244
Figure 6-9. Simple correspondence analysis from 1999 to establish the relationship between the health rating given to each sampled plant and the incidence of specific fungi isolated from four fungicide treatments 246
Figure 6-10. Incidence of *Aspergillus flavus* measured as the proportion of infected plants sampled from plots sprayed with four different fungicides in commercial fields in Santa Rosa County, Florida, in 1998 (A) and 1999(B) 248
Figure 6-11. Incidence of *Aspergillus niger* measured as the proportion of infected plants sampled from plots sprayed with four different fungicides in commercial fields in Santa Rosa County, Florida, in 1998 (A) and 1999(B) 249
Figure 6-12. Incidence of *Cylindrocladium parasiticum* measured as the proportion of infected plants sampled from plots sprayed with four different fungicides in commercial fields in Santa Rosa County, Florida, in 1998 (A) and 1999(B) 250
Figure 6-13. Incidence of *Fusarium* spp. measured as the proportion of infected plants sampled from plots sprayed with four different fungicides in commercial fields in Santa Rosa County, Florida, in 1998 (A) and 1999(B) 251
Figure 6-14. Incidence of *Lasiodiplodia theobromae* measured as the proportion of infected plants sampled from plots sprayed with four different fungicides in commercial fields in Santa Rosa County, Florida, in 1998 (A) and 1999(B) 252
Figure 6-15. Incidence of *Macrophomina phaseolina* measured as the proportion of infected plants sampled from plots sprayed with four different fungicides in commercial fields in Santa Rosa County, Florida, in 1998 (A) and 1999(B) 253
Figure 6-16. Incidence of *Neocosmospora vasinfecta* measured as the proportion of infected plants sampled from plots sprayed with four different fungicides in commercial fields in Santa Rosa County, Florida, in 1998 (A) and 1999(B) 254

Figure 6-17. Incidence of *Phomopsis* sp. measured as the proportion of infected plants sampled from plots sprayed with four different fungicides in commercial fields in Santa Rosa County, Florida, in 1998 (A) and 1999(B) 255
Figure 6-18. Incidence of *Pythium* spp. measured as the proportion of infected plants sampled from plots sprayed with four different fungicides in commercial fields in Santa Rosa County, Florida, in 1998 (A) and 1999(B) 256
Figure 6-19. Incidence of *Rhizoctonia solani* measured as the proportion of infected plants sampled from plots sprayed with four different fungicides in commercial fields in Santa Rosa County, Florida, in 1998 (A) and 1999(B) 257
Figure 6-20. Incidence of *Rhizopus* spp. measured as the proportion of infected plants sampled from plots sprayed with four different fungicides in commercial fields in Santa Rosa County, Florida, in 1998 (A) and 1999(B) 258
Figure 6-21. Incidence of *Sclerotium rolfsii* measured as the proportion of infected plants sampled from plots sprayed with four different fungicides in commercial fields in Santa Rosa County, Florida, in 1998 (A) and 1999(B) 259
Figure 6-22. Incidence of *Trichoderma* spp. measured as the proportion of infected plants sampled from plots sprayed with four different fungicides in commercial fields in Santa Rosa County, Florida, in 1998 (A) and 1999(B) 260
Figure 7-1. Development of the foliar canopies associated with three rates of chlorothalonil (0 g ha^{-1}, and 2040 g ha^{-1}) sprayed for control of leaf spot and rust in peanut..... 285
Figure 7-2. The effect of the rate of the fungicide chlorothalonil applied on a biweekly basis throughout the season on the yield of peanut in a commercial peanut field in Suwannee County, Florida, in 1998 286
Figure 7-3. The effect of the rate of the fungicide chlorothalonil applied on a biweekly basis on the area under the disease progress curve (AUDPC) for the severity of foliar disease in a commercial field in Suwannee County, Florida during 1998 287
Figure 7-4. The effect of the application of the fungicide chlorothalonil on the area under the disease progress curve (AUDPC) associated with soilborne disease in a commercial field in Suwannee County, Florida during 1998..... 288
Figure 7-5. Incidence of *Aspergillus flavus* measured as the proportion of infected peanut plants sampled on each date from plots that received three different rates of chlorothalonil (0 g ha^{-1}, 680 g ha^{-1}, and 2040 g ha^{-1}) for control of foliar fungal diseases in a commercial field in Suwannee County, Florida in 1998 290

Figure 7-6. Incidence of *Aspergillus niger* measured as the proportion of infected peanut plants sampled on each date from plots that received three different rates of chlorothalonil (0 g ha^{-1}, 680 g ha^{-1}, and 2040 g ha^{-1}) for control of foliar fungal diseases in a commercial field in Suwannee County, Florida in 1998 291
Figure 7-7. Incidence of *Fusarium* spp. measured as the proportion of infected peanut plants sampled on each date from plots that received three different rates of chlorothalonil (0 g ha^{-1}, 680 g ha^{-1}, and 2040 g ha^{-1}) for control of foliar fungal diseases in a commercial field in Suwannee County, Florida in 1998 292
Figure 7-8. Incidence of *Lasiodiplodia theobromae* measured as the proportion of infected peanut plants sampled on each date from plots that received three different rates of chlorothalonil (0 g ha^{-1}, 680 g ha^{-1}, and 2040 g ha^{-1}) for control of foliar fungal diseases in a commercial field in Suwannee County, Florida in 1998 293
Figure 7-9. Incidence of *Macrophomina phaseolina* measured as the proportion of infected peanut plants sampled on each date from plots that received three different rates of chlorothalonil (0 g ha^{-1}, 680 g ha^{-1}, and 2040 g ha^{-1}) for control of foliar fungal diseases in a commercial field in Suwannee County, Florida in 1998 294
Figure 7-10. Incidence of *Neocosmospora vasinfecta* measured as the proportion of infected peanut plants sampled on each date from plots that received three different rates of chlorothalonil (0 g ha^{-1}, 680 g ha^{-1}, and 2040 g ha^{-1}) for control of foliar fungal diseases in a commercial field in Suwannee County, Florida in 1998 295
Figure 7-11. Incidence of *Phomopsis* sp. measured as the proportion of infected peanut plants sampled on each date from plots that received three different rates of chlorothalonil (0 g ha^{-1}, 680 g ha^{-1}, and 2040 g ha^{-1}) for control of foliar fungal diseases in a commercial field in Suwannee County, Florida in 1998 296
Figure 7-12. Incidence of *Rhizoctonia solani* measured as the proportion of infected peanut plants sampled on each date from plots that received three different rates of chlorothalonil (0 g ha^{-1}, 680 g ha^{-1}, and 2040 g ha^{-1}) for control of foliar fungal diseases in a commercial field in Suwannee County, Florida in 1998 297
Figure 7-13. Incidence of *Rhizopus* spp. measured as the proportion of infected peanut plants sampled on each date from plots that received three different rates of chlorothalonil (0 g ha^{-1}, 680 g ha^{-1}, and 2040 g ha^{-1}) for control of foliar fungal diseases in a commercial field in Suwannee County, Florida in 1998 298
Figure 7-14. Incidence of *Trichoderma* spp. measured as the proportion of infected peanut plants sampled on each date from plots that received three different rates of chlorothalonil (0 g ha^{-1}, 680 g ha^{-1}, and 2040 g ha^{-1}) for control of foliar fungal diseases in a commercial field in Suwannee County, Florida in 1998 299

Figure 7-15. Incidence of *Zygorhynchus* sp. measured as the proportion of infected peanut plants sampled on each date from plots that received three different rates of chlorothalonil (0 g ha^{-1}, 680 g ha^{-1}, and 2040 g ha^{-1}) for control of foliar fungal diseases in a commercial field in Suwannee County, Florida in 1998 300
Figure 7-16. Simple correspondence analysis from 1998 to establish the relationship between the time of sampling and the incidence of specific fungi isolated from three treatments for control of foliar diseases 302
Figure 7-17. Simple correspondence analysis from 1998 to establish the relationship between the parts of the plant and the incidence of specific fungi isolated from three treatments for control of foliar diseases 304
Figure 7-18. Simple correspondence analysis from 1998 to establish the relationship between the health rating given to each sampled plant and the incidence of specific fungi isolated from three treatments for control of foliar diseases 307

Abstract of Dissertation Presented to the Graduate School
Of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Doctor of Philosophy

A CHARACTERIZATION OF THE SOILBORNE FUNGI ASSOCIATED WITH PEANUT (*ARACHIS HYPOGAEA* L.) IN FLORIDA

By

Robert C. Kemerait, Jr.

May 2000

Chairman: Thomas A. Kucharek
Major Department: Plant Pathology

Forty-eight genera of fungi were isolated from roots, pods, pegs, and hypocotyls of peanut grown in Florida. Most were non-pathogenic when inoculated into wounded plants. Common pathogens included *Cylindrocladium parasiticum, Sclerotium rolfsii, Lasiodiplodia theobromae, Aspergillus niger, Rhizoctonia solani, Neocosmospora vasinfecta* and *Fusarium* spp. Virulence of some pathogens was affected by the age of the plant and by temperature. *Trichoderma* sp. and *Chaetomium* sp. were antagonistic to pathogens such as *S. rolfsii* and *R. solani* on agar plates.

Two communities of soilborne fungi were associated with progressive growth stages of peanut. A general community progressed through foundational, secondary, and tertiary stages of development. The tertiary stage was associated with development of the foliar canopy. Relative humidity within the developed canopy increased, and the ambient temperature and the soil

temperature in the pegging-zone decreased, as the season progressed. Such changes could have enhanced infection by some pathogens. The peg community also emerged during this period; these fungi were specifically associated with pegs (gynophores) and linked to the foliage of the peanut.

Severity of soilborne disease was greater in Florunner than in Florida MDR 98 or Georgia Green. Infection of Florunner by *C. parasiticum* occurred earlier than it did for the other two varieties. The fungicides tebuconazole and flutolanil increased yields, reduced the severity of soilborne diseases, and were associated with a reduction in the incidence of *S. rolfsii*. When evaluating fungicides for foliar pathogens, chlorothalonil reduced the severity of peanut rust and increased yields but did not affect the severity of soilborne disease. Incidence of soilborne pathogens was low in the field where this study was conducted. Uses of fungicides and different cultivars of peanut were not associated with major changes in the communities of fungi.

Descriptions of the fungal communities were based on surveys of multiple sites in 1995 and 1996. The characters of these communities varied slightly in individual fields. For example, distinction between the foundational and secondary stages was less obvious, and the placement of *S. rolfsii* and *L. theobromae* within communities varied. Crop rotation, planting date, soil fertility levels, and parasitic nematodes influenced the incidences of specific fungi.

CHAPTER 1
INTRODUCTION

Peanut, *Arachis hypogaea* L., is an important crop in Florida and is grown widely in the northern and northwestern parts of the state. Florida ranked fifth in the nation for peanut production in 1997 (8). In 1998, growers in the state planted this crop on approximately 39,660 hectares and harvested nearly 106,000 metric tons of peanuts (6). The yield was valued at more than 57 million dollars and peanut continued to rank among the 20 most valuable farm products in Florida.

The peanut crop is particularly vulnerable to soilborne diseases as both the roots and fruits (pods) of the plant grow in the soil. Diseases caused by soilborne, fungal pathogens reduce yields and the quality of the harvested pods. These diseases affect the crop from planting until harvest. Some diseases, such as seedling blights caused by *Pythium myriotylum* Drechs. and *Rhizoctonia solani* Kuhn, and Aspergillus crown rot, are important on younger plants (20, 31, 123). Other diseases, such as southern stem blight, caused by *Sclerotium rolfsii* Sacc., and peanut pod rot, caused by a complex of pathogens, are more important on older plants later in the season (9, 55). Growers use a combination of tactics to manage all of these diseases.

Control of soilborne diseases of peanut is difficult. Cultivars that are planted in Florida, such as Georgia Green and Florida MDR 98, may have partial

resistance to some soilborne diseases; however, complete resistance does not exist (114). Differences between the incidences of soilborne fungi that infect susceptible cultivars versus cultivars with partial resistance to soilborne diseases are not well established. Fungicides are also used to control the soilborne diseases; however there are only a few effective chemicals available to the grower (124).

To determine the optimum period for the application of the chemicals that are available is complicated because the early symptoms of disease are hidden beneath the soil. While the grower can observe early symptoms of foliar diseases such as rust and leaf spots, it is more difficult to discover lesions on the roots and pods. If applications of fungicides are delayed until symptoms became visible, it is too late to obtain adequate control of the disease. Because of the absence of observable symptoms at the start of an epidemic, growers in Florida are advised to begin applications of fungicides for the control of both southern stem blight and Cylindrocladium black rot, caused by *Cylindrocladium parasiticum* Crous, Wingfield & Alfenas, 45 days after planting (114). In studies where the efficacies of fungicides for control of soilborne pathogens of peanut were evaluated, the optimal periods for the application of these chemicals were often determined based upon treatments that best increased yields or suppressed disease (16, 32, 53). Information on the time of infection of the host by the pathogens was not available to determine the best fungicide application dates in these studies or for the growers in Florida.

Despite the adverse effects of soilborne diseases on peanut production in Florida and throughout the world, basic information about the structure of the community of fungi in which the pathogens exist is scant. The soilborne fungi found in association with pods during the later stages of development and at maturity have been documented (12, 13, 14, 19, 75, 86, 95, 97, 99). A general list of fungi, both epiphytic and soilborne, found in association with the peanut also has been compiled from a number of sources (67). With the exception of limited work by Garren (75) and Jackson (99), these studies do not describe ecological relationships between the fungi and the host. Information about changes in the incidences of fungi as functions of the growth of the host, the time of the season, and the part of the host that is colonized does not exist. Similar studies have been done for a limited number of other hosts (62, 126, 185).

Many soilborne fungi isolated from peanut pods have been identified (12, 13, 14, 19, 75, 86, 95, 97, 99) and soilborne diseases and pathogens of peanut are well described in the literature (106, 124). However, basic information about the patterns of fungal incidence in peanut across a region and variables that affect these patterns is not available. Access to such information would be of general interest to anyone who is involved in the development tactics for disease control on a regional basis and the education of the peanut grower.

Given the lack of information available on the soilborne fungi associated with peanut, the objectives of this research were to:

1. identify the soilborne fungi that are found in association with specific parts of peanut plants in Florida;

2. evaluate the pathogenicity of some of the common soilborne fungi found in association with the peanut plant;
3. evaluate potential interactions between common soilborne fungi isolated from the peanut plants;
4. seek ecological evidence of relationships, distinct fungal groups or succession within the observed fungi;
5. observe the relationship between the age of the crop, its growth stage, and the incidence of selected fungi including important pathogens;
6. assess the effect of fungicide treatments and different cultivars on the incidence of specific soilborne fungi;
7. assess the influence of variables such, as crop rotation, soil fertility, and nematode populations, on the incidence of specific fungi.

To identify the structure of a community of soilborne fungi that is associated with peanut would provide a foundation against which to compare possible changes in the mycoflora infecting the crop in the future. Shifts in the composition of the mycoflora could result from changes in weather patterns, development of novel cropping practices, improved disease control tactics and fungicides, introduction of new cultivars, or the emergence of new pathogens. As precision agriculture becomes increasingly popular and society demands rationale for use of all pesticides, results from a study, such as this one, that better describe a component of a pathosystem could lead to more effective applications of fungicides and deployment of other tactics.

CHAPTER 2
LITERATURE REVIEW

Arachis hypogaea L.

Peanut, *Arachis hypogaea* L., is an important crop in many areas of the world and is found throughout the tropical, subtropical, and warm temperate regions between 40° north and 40° south latitudes (4, 85). The fruits, or "nuts," of the peanut are very nutritious and are unusual because of their development within the soil. Peanuts are high in calories and contain approximately 25% protein. The seeds contain fiber, vitamin E, riboflavin, thiamine, and potassium and are characterized by a high oil content that varies between 44% and 56% (2, 44, 106). The nuts may be eaten raw, cooked, or processed for oil, and are an important part of the diet in many areas of the world.

Most of the peanut crop that is produced in the United States is shelled and sold for peanut butter, salted peanuts, and confections (2, 106). In some countries of the semiarid tropics of Africa, subsistence farmers consume over half of the total production directly as a food source (4). However, it is estimated that at least 80% of the world's peanut crop is used in the production of cooking oil. For example, nearly all of the peanuts grown in India are used for oil (4).

Although the United States leads the world in the amount of peanuts produced per cultivated area, India and China are the largest producers (106). In 1998, India produced 8.0 million metric tons of peanuts. In the same year,

China produced 9.65 million metric tons, while the United States produced 1.6 million metric tons (5). Other important peanut-producing nations include Senegal, Indonesia, Burma, Zaire, Sudan, Nigeria, Cameroon, and Argentina (106).

Peanuts are grown in three main regions within the United States. The southeastern region includes Alabama, Florida, Georgia, and South Carolina. Georgia is the largest peanut producing state with 685,559 metric tons reported in 1998, and Alabama is the third largest with 196,106 metric tons reported that same year (7). The southwestern region includes New Mexico, Oklahoma, and Texas. Texas is the nation's second largest producer of peanuts and reported 416,281 metric tons produced in 1998 (7). The final region includes Virginia and North Carolina (106, 155). An estimated 54.6% of the peanuts produced in the United States are grown in the southeastern region, 28.4% in the southwestern region, and approximately 14.7% in the Virginia-Carolina region (8).

Florida ranked fifth in the nation for total peanut production in 1997 (8). An estimated 39,660 hectares were planted to peanuts in 1998, with a yield valued at over 57 million dollars. Of this area, 36,420 hectares were harvested for dry nuts, while the remaining acreage was used for green nuts, hay, pasture, or were abandoned. The statewide production for 1998 was reported as 105,714 metric tons, with an average yield of 2.9 metric tons per hectare (6).

Of the peanuts produced in Florida, most are grown in the north-central and panhandle regions. The counties with the largest acreage in peanuts during 1998 included Jackson (13,072 hectares), Santa Rosa (5,868 hectares), Levy

(4,087 hectares), Suwannee (2,307 hectares), Marion (2,023), Holmes (1,983 hectares), and Calhoun (1,740 hectares). The counties from which the largest production was reported in 1998 were Jackson (35,692 metric tons), Santa Rosa (18,096 metric tons), Levy (12,400 metric tons), Suwannee (6,549 metric tons), and Calhoun (5,207 metric tons) (6).

Origin of the Peanut

Arachis hypogaea L. originated in South America and was grown widely by pre-Columbian peoples of the tropics and subtropics in the western hemisphere. Early European explorers found the peanut being grown in Mexico, the northeastern coast of Brazil; across Peru; in the Rio de la Plata region of Argentina, Paraguay, and Bolivia; and several islands in the West Indies. All of the wild species of the genus *Arachis* are confined to South America; the center of diversity appears to be in the Mato Groso area of Brazil. The peanut disseminated from South and Central America to Europe, Africa, Asia, and the Pacific Islands. Peanut was later introduced to the colonial seaboard of what was to become the southeastern United States. Apparently, a two-seeded Brazilian type found its way to Africa and the coast of Malabar of southwest India. The three-seeded Peruvian type was taken to the western Pacific, China, India, and Madagascar (85).

Taxonomy

The peanut is a member of the family Fabaceae (Leguminoseae) and the genus *Arachis*. It belongs to the species *Arachis hypogaea* L. that is divided into two subspecies. *Arachis hypogaea* L. ssp. *hypogaea* is characterized by 1) a

central axis which does not bear inflorescences, 2) lateral branches in which two vegetative branches alternate with two reproductive branches, and 3) a plant growth habit that is normally prostrate. The inflorescences are simple, the pods contain two or three seeds, and these seeds show dormancy. The subspecies contains two botanical varieties: variety *hypogaea* (Virginia and runner types) and variety *hirsuta* (Peruvian humpback) (158, 184). Maturity in the *hypogaea* variety is normally reached between 145 and 165 days after planting (155). However, breeding programs have reduced the maturing period for some cultivars. For example, the runner cultivar Andru 93 matures in 125 days (E. B. Whitty, personal communication).

The majority of the peanuts grown in Florida are of the runner type, though some Virginia-market-types are grown as well. Important runner cultivars grown in recent years include Florunner, Sun Runner, Georgia Green, GK-7, SunOleic 97R, Florida MDR 98, Southern Runner, ViruGard, and Andru 93. Florunner had been the favored runner cultivar in the southeast until recently. In 1982, it was estimated that 98% of peanuts planted there were Florunner. Nearly 100% of the peanuts grown in the Virginia-Carolina region are of the Virginia type (93). Virginia-market-type varieties of interest in Florida include NC 7, NC 9, NC 10C, NC 12C, and NC V11 (183).

The second subspecies is *Arachis hypogaea* L. ssp. *fastigiata*. This taxon is distinguished by 1) erect growth habit, 2) inflorescences along the central axis, and 3) no regular pattern for the sequence of reproductive and vegetative branches. The inflorescence may be simple or compound, the seeds do not show

dormancy, and the fruit normally mature between 125 and 145 days after planting (155, 184). There are four varieties recognized in the subspecies *fastigiata*. These are variety *fastigiata* (market-type Valencia), variety *peruviana*, variety *aequatoriana*, and variety *vulgaris* (market-type Spanish) (158). Although Valencia cultivars are grown in Florida for boiling peanuts, the acreage is usually small and makes up only 8% of the total area planted. In 1998, Valencia cultivars were grown on approximately 3,238 hectares in Florida (6). In 1997, 73% of the peanuts grown in the United States were runner-type, 22% were Virginia types, approximately 4% were Spanish types, and less than 1% were Valencia cultivars (8).

The Peanut Plant

The peanut is an annual legume, and, depending on the subspecies, it may be either erect or prostrate in growth habit. Plant height ranges between 15 and 60 cm. The aerial stems may be sparsely hairy, while the taproot and lateral roots are normally devoid of hair or a distinct epidermis (142). The peanut leaves are pinnately compound and typically have two opposed pairs of leaflets that range from 2-5 cm in length. The leaf petioles are 3-7 cm in length. Flowers are borne on inflorescences located in the axils of leaves, but are not found nodes of a vegetative branch. Leaf axils may contain one to several flowers. Each flower has five yellow-to-orange petals, including a standard, two wings, and a keel, formed from two fused petals. The flowers have 10 monadelphous stamens (142). The flowers possess a long hypanthium or calyx tube (80). Seeds of the cultivated peanut are variable in shape, size, and color.

The seeds are composed of two large cotyledons, an upper stem axis with young foliage leaves (epicotyl), a lower stem axis (hypocotyl), and a primary root (radicle). The seed is enveloped within a papery seed coat. The leaves and aerial parts of the seedling present for the first 2 or 3 weeks of growth are present in the seed (50). The radicle begins to grow from the seed between 24 and 48 hours after planting, though it takes approximately a week for the shoot (epicotyl) to emerge. The root initially grows much more rapidly than the shoot and may reach the length of 10-40 cm in only 5 days. No lateral roots develop within the first 48 hours, but many have formed by the age of 5 days. After approximately 12 days, the root system may reach a length 30 cm, while the shoot begins to expand with foliage leaves that were present in the seed. No new foliage growth is observed until about 3 weeks after planting (80).

The transition between the root and stem is clearly differentiated on the young seedling by an abrupt constriction between the hypocotyl and the radicle. At this junction, the intact epidermal layer of the hypocotyl ends, and the non-epidermal layers of the root begin. A true epidermis is lacking on the peanut roots, and they are generally devoid of any hairs. At this transition, the arrangement of the vascular strands changes from the radial pattern found in the root to a collateral pattern, as found in the stem, and tannin cells associated with the collateral bundles are immediately apparent.

In the peanut seedling, the hypocotyl is defined as the portion of the peanut stem lying below the cotyledons and above the root. The hypocotyl becomes a part of the plant's anchoring system and never emerges from the soil.

During the seedling stage, the healthy hypocotyl is very succulent and quite smooth. The length of the hypocotyl is dependent on the depth at which the seeds were planted. Thus, seeds that are planted at greater depths will have seedlings with longer hypocotyls. Important changes occur in the hypocotyl beginning 10-30 days after planting. The epidermis and succulent cortex collapse, become soft, and may be rubbed off. As this occurs, the collar at the junction of the root and hypocotyl becomes very hard. The pith within the hypocotyl breaks down, and the region becomes a hollow, woody axis (80). As the cortex is lost, a continuous cylinder of cork cambium and outer sloughing tissue extends from the root to the cotyledon. The central cylinder of the hypocotyl continues to grow and becomes woody. In extreme cases it may reach a diameter of 1.9 cm and is often referred to as the "taproot" (81). The taproot is well developed in the mature root system and may penetrate cultivated soil to depths in excess of 1 meter. The root system has abundant lateral roots and fibrous rootlets. Adventitious roots may develop from the hypocotyl and aerial branches (81).

The morphological structure of the epicotyl is present within the seed. The epicotyl consists of three axes, a main axis of the central stem and two lateral axes. The main axis develops first, but it may be quickly equaled in length by the lateral shoots. The erect primary branch occurs in all varieties of cultivated peanuts and is the main axis of the plant. In prostrate varieties, this primary branch may be relatively short, though still erect. The main axis branch gives rise to a number of lateral branches. In erect varieties, these lateral

branches are also erect. In prostrate varieties, the lateral branches grow peripherally away from the primary branch and may lie close to the ground (81).

Flowering in the peanut begins 4 to 6 weeks after planting, and is followed by a slow increase in the rate of flower production (80,106). This rate of floral production greatly increases 2 or 3 weeks after the first flowers form and reaches a peak some 3 to 4 weeks later. The rate of flower production then decreases at a rate similar to the rate of increase (80). The flowers are self-pollinated in the early morning near sunrise (155). The flowers, fresh and turgid at dawn, are usually wilted by midday (80, 155). The day after flowering, all of the floral parts, with the exception of the ovary, have withered, and the hypanthium has usually detached from it. The gynophore, or "peg", on which the ovary is borne begins to grow and elongate immediately after fertilization occurs. Initially, growth of the peg is slow, but the rate increases. The peg is positively geotropic but it is not negatively phototropic. The length attained by the peg is dependent on the initial distance between the branch and the soil surface. Normal pod development will not occur if the peg cannot penetrate the soil surface (80).

Once the peg penetrates the soil, it continues to grow to a depth approximately 2 to 7 cm below the surface. At this point, the peg may become thickened and develop multicellular trichomes. Eventually the peg loses its geotropism, and the tip aligns itself horizontal to the soil surface. As this occurs, the pod begins to enlarge and develops rapidly. The enlargement proceeds from the basal to the apical region and the basal seed develops earlier than the apical. During development, the exopcarp of the fruit is sloughed off and the

ridged sclerenchymatous mesocarp is exposed. The cells of the endocarp collapse as the pod matures. At maturity, the pod is reticulated and constricted between the seeds. The fruit is a single-loculed, structurally dehiscent, but functionally indehiscent pod (80).

In 1982, Boote (25) presented a system to distinguish the growth stages of the peanut plant based upon visual inspections. The plant growth was divided between vegetative and reproductive phases. Vegetative phases were described based upon the number of developed nodes on the main axis of the peanut plant, beginning with the cotyledonary node as "V0." Reproductive stages were based upon visually observable events that were related to flowering, pegging, fruit growth, seed growth, and maturity. The system proposed by Boote enables one to decrease reliance on the calendar age of the crop and to consider morphological characteristics to describe host development. A summary of these growth stages is listed in Table 3-5.

Peanut Production Practices in the United States

> Successful peanut production can be achieved only as each cultural practice is effectively integrated into the total production program. The ineffective implementation of any single practice can severely reduce crop production potential. (93)

The following is a brief overview of practices and considerations used in the growing of peanuts in the United States today. The introductions of new cultivars, pesticides, and machinery have made the culture of peanuts very different than it was 40 years ago. The practices in use today are important to maximize yield and profits and are to maintain peanut health and to reduce the opportunity for diseases to develop.

Site selection is an important first step to grow peanuts. Peanuts grow best in deep, well-drained soils with a friable surface. Such soils include sands, sandy loams, and sandy clay loams (93). Sandy soils are beneficial for several reasons. Sandy, well-drained soils do not lead to pod discoloration caused by organic matter or iron oxides. The developing peg is able to penetrate sandy soils more easily than it can compacted soils. If the soil is fine textured and compact, pod size may be reduced. Finally, the harvesting becomes more efficient because it is easier to dig the peanuts. A negative aspect of planting peanuts in sandy soils is the rapidity at which they dry. For optimal production, peanuts require 56-64 cm of water during the growing season, especially during the fruiting stages. Sandy soils are poor at retaining moisture in the root zone. Also, because of nutritional needs to be discussed later, developing pods require that calcium be available from the ambient soil. Dry soils inhibit the movement of calcium to that ambient environment (49, 93).

The cropping history of the selected site can be an important consideration, and crop rotation is often used to reduce the amount of pathogenic inoculum in a field. In theory, the level of inoculum is reduced by alternating non-host crops with susceptible ones on a periodic basis. Beneficial crops for rotation with peanuts include pasture grasses, sorghum, and corn. Soilborne diseases may be more severe when cotton, tobacco, and soybeans are included in the rotations (93). Whenever possible, growers are advised to maintain a 3 to 4 year interval between peanut crops (49, 114). In addition to reducing nematode problems and soilborne diseases, good crop rotation can

result in an effective use of residual soil fertilization and improved efficiency in the control of certain weeds (49, 93).

There are two general practices for land preparation to grow peanuts. With conventional tillage, a primary and a secondary tillage are used for the management of weeds, pathogens, and the preparation of a friable bed. In primary tillage, a moldboard plow is used to deep turn the soil and bury all organic matter and debris at least 15 cm deep. This also helps to bury the survival structures of certain soilborne pathogens and helps to deprive pathogens of a nutritional source between crops (49,114). Deep plowing also aids in the burial of weed seeds and in the incorporation of fertilizers and applied lime (93). During secondary tillage, the field is disked to provide a suitable seed bed. A raised seed bed can improve drainage, warm the soil, and improve aeration. Peanuts should not be planted in soils cooler than 18° C (65° F) (49). Seeds planted in cooler soils have less vigorous germination, and the seedlings are more vulnerable to disease.

To reduce costs of production, some growers use conservation tillage practices. These include no-till, minimal tillage, reduced tillage, and strip tillage. In no-till, the seeds are planted directly into previously undisturbed soil. In minimal tillage, the grower performs the least soil disturbance necessary to plant the seeds. Strip tillage involves bed preparation in the narrow band where the seeds will be planted. Pod yields have been reported to be lower when conservation tillage is used (49), and growers who have tried conservation tillage practices have expressed mixed feelings on its worth to grow peanuts. Better

results seem to be attained when all organic matter and debris is cleared from the seedling emergence zone (114).

In *Peanut Health Management* it is stated: "The health of a peanut plant is not solely linked to the presence or absence of a disease; many factors influence plant health" (104). To maximize the quality and yield of a peanut crop, there are a number of measures that a grower can take to protect the peanut plants. Seeds hold the genetically determined yield potential of a peanut crop. Selection of the cultivar by the grower is very important and should be made carefully, based upon specific individual considerations (164). The grower must use high quality seed that germinates with high vigor (104, 114). Vigorous seedlings are less likely to be affected by fungi such as *Rhizoctonia solani* Kuhn and *Pythium* spp., which are responsible for seedling blights (114). Cool, wet soils lead to slow seed germination. Slow germination of seeds can be linked to an increase in seed rot and seedling blight (93). In Florida, peanuts have been planted traditionally between April 10 and May 10 when the soil temperatures are sufficiently warm. Peanuts planted earlier in the season may yield better than later plantings, and early plantings may also reduce some of the disease that results from poor crop rotation (93). However, with the emergence of tomato spotted wilt virus as a major problem for peanut growers, planting dates have been modified to reduce the severity of this disease.

Many growers apply lime to their fields prior to planting and later apply gypsum (calcium sulfate) as the crop enters the reproductive-pegging phase. Lime is applied for the dual purpose to elevate soil pH and to increase the

calcium ion (Ca^{++}) concentration in the pegging zone. The soil pH should be above 5.8 for best yields and pod quality. Lime is often added to the soil several months prior to planting to raise the pH (93). The importance of Ca^{++} in the pegging zone is well recognized (49, 50, 114). Cox et al. (50) claim that peanut yields are limited more often by a lack of calcium than by any other nutrient in the coarse-textured soils in the United States. The need for extra calcium makes the peanut unique among common crops (49). The calcium ions are transported almost exclusively within the xylem tissue and are carried upwards with the transpiration stream. Little or no Ca^{2+} is transported down from the leaves through the phloem tissue. Once the peg has penetrated the soil, it ceases to transpire water absorbed by the roots and access to this calcium source is blocked. The Ca^{2+} needed by the pegs and developing pods must be absorbed directly from the soil by the pods (49, 50). Deficiencies of calcium in the pegging zone can lead to empty pods, "pops," black plumule in the seed, and reduced pod formation. Poor development of the pods can predispose the plant to pod rots caused by soilborne fungi (114). A deficiency of calcium or an imbalance with other elements has been cited as the primary cause of peanut pod rot (55, 56, 57). The importance of the soilborne fungi, such as *R. solani*, *P. myriotylum*, and *F. solani*, in pod rot was of secondary importance with respect to insufficient levels of Ca^{++}. However, the level of calcium in the pod had minimal impact on rots caused by *Cylindrocladium parasiticum, Sclerotinia minor*, and *Sclerotium rolfsii* (55). In Oklahoma, Filonow et al. (68) found that increased levels of

calcium did not decrease peanut pod rot, and that *P. myriotylum* and *R. solani* were primarily responsible for the disease.

To produce the healthiest pods, the Ca^{2+} concentration in the pegging zone that envelopes the pods should exceed some critical level (50). This level has been reported to be 340-570 kg/ha (300-500 pounds per acre) for runner cultivars and at least 1700 kg/ha (1500 pounds per acre) for Virginia cultivars (49). Lime ($CaCO_3$) and gypsum ($CaSO_4 \cdot 2H_2O$) are often used to increase the concentration of calcium in the soil. Gypsum is used as a soil amendment; however it may be leached more easily than lime from the soil.

The best time to harvest peanuts is often difficult to assess because the fruits are buried in the soil, and the flowering pattern of the plant is indeterminate (151). Harvest at proper pod development insures that a high percentage of the pods are mature and that fewer pods are prematurely detached from the pegs during the digging and inverting phases. There are currently two common methods to determine the maturity of the peanut fruit. The first method is referred to as the "shellout maturity test" and is based upon changes in the colors of the interior of the hull and the seed coats as the pods mature. The grower is able to decide when to dig the peanuts based upon the percentage of mature pods obtained from a number of plants sampled in the field (151). The second method is referred to as the "hull-scrape maturity test" and is now considered to be the most accurate method to determine the optimum time to dig the peanuts (151). This test is based on the color of the mesocarp of the peanut pod as it changes from white to yellow to orange to brown to black as the pod

matures. Plants are collected from around the field, and all of the pods are picked from each plant. The total number of pods should be between 180 and 220. The maturity of the crop is determined by removing the tan-colored exocarp in the "saddle" portion of the pods to expose the mesocarp. The pods are grouped on a chart based upon the colors of the moistened mesocarps. The digging date is determined based upon the intersection between the slope line and the harvest projection lines on the chart.

Soilborne Fungi

Peanut is unusual because both the root system and the fruits develop within the soil and are accessible to invasion by numerous fungi, pathogenic and non-pathogenic, which reside in this habitat. It is difficult to determine an exact figure for peanut losses in Florida that result from diseases caused by soilborne fungi, but it is considerable (Kucharek, personal communication). In peanuts, these organisms are responsible for seed rots, seedling blights, damping-off disease, stem and root rots, and peg and pod rots. They are difficult to control for a variety of reasons that include wide host ranges, their ability to survive as saprophytes, and the ability of some fungi to form durable survival structures which can remain viable in the soil for long periods of time (87). The interactions between the plant host, soilborne fungi, and the environment are complex and interrelated.

Biologists have traditionally defined fungi as "eukaryotic, spore-producing, achlorophyllous organisms with absorptive nutrition that generally reproduce sexually and asexually and whose usually filamentous branched somatic cells,

known as hyphae, typically are surrounded by cell wall" (3). Most fungi are classified in the Kingdom Fungi or Eumycota, but others, such as the Oomycota and the Plasmodiophoromycota, are included in the Kingdoms Chromista and Protozoa, respectively (92).

In this dissertation, the term "soilborne fungi" will refer to those fungi whose primary ecological niche is within the soil or within structures enveloped by the soil such as plant roots or organic debris. In Ainsworth and Bisby's Dictionary of the Fungi, 8th Edition (92), these fungi are described as important to keep the soil fertile and include plant pathogens. The chief work of soil fungi relates to the decomposition and recycling of organic residues, such as in the early stages of the decomposition of plant material. Garrett (77) characterized soilborne fungal pathogens as either "soil-inhabiting" or as "root-inhabiting." Soil inhabitants were described as being able to survive indefinitely as saprophytes. Root-inhabitants have a reduced distribution in the soil and are predominantly composed of parasitic root-infecting fungi with less ability to survive as saprophytes. Pathogenic fungi found within the group of "soil inhabitants" are described as primitive parasites able to survive indefinitely as saprophytes. These primitive pathogens are found to infect seedlings, young roots, and roots of plants growing under stressed conditions, but have not lost a competitive saprophytic ability (78). Examples of soil-inhabiting parasites presented by Garrett (78) include *R. solani* and *Pythium* spp. Root-inhabiting fungal pathogens are described as the major soilborne plant pathogens. These fungi are highly specialized parasites with host specificity and a delayed destruction of

the host. Garrett (78) believed that these fungi have a transitory existence in the soil in the absence of a host. He viewed the two groups as incompatible with each other; pathogenic specialization was incompatible with a well-established saprophytic existence.

Fungal pathogens which infect the foliage and above-ground portions of a plant may not be present in close proximity to the host when it is planted in the field. Pathogens that cause leaf spots and rust, for example, may be blown into the field from great distances. However, the propagules of soilborne pathogens are likely to be present in close proximity when the seeds or transplants are introduced into the field. Propagules of soilborne fungi may also be seed-borne (102, 180). Dormant fungal propagules within the soil act as survival structures that allow the pathogen to exist until a suitable host is present. The dormant propagules can be grouped into the following three categories: dormant mycelia; short term survival structures, such as conidia, ascospores, and zoospores; and structures which can survive for weeks, months, or even years such, as oospores, chlamydospores, and sclerotia (133).

Germination of these propagules, or a release from the dormant state, is likely to be initiated by the diffusion of root-exudates from a suitable host (98, 129). Therefore, the maximum distance at which a pathogenic propagule can respond to the host is affected by the ability of the exudates to diffuse within the soil and the ability of the germinated propagule to reach the root. This zone of soil affected by the root exudates is known as the rhizosphere and extends approximately 1 millimeter from the root prior to any microbial activity and shrinks

once microbial activity is initiated (98). Other factors that may be important in fungal development and growth from a propagule include soil temperature, moisture, aeration, and soil pH (47). Stress conditions may also increase the amount of root-exudates in some hosts (117).

Inventories of Soilborne Fungi

The soilborne fungi associated with peanut pods have been documented in several studies. Garren (75) was one of the first researchers to identify many of the important fungi associated with both rotted and sound pods. In his study, Garren (75) found that both *Trichoderma viride* and *Penicillium* spp. were dominant fungi in both sound and diseased pods. *Aspergillus niger* and *Aspergillus flavus* were found to persist throughout the development of the pods but were never very common. Other fungi that were recovered from the developing pods included *Fusarium* spp., *Chaetomium* spp., *P. myriotylum,* and *R. solani.*

Jackson (99) evaluated the fungi associated with pods from the cultivars Argentine, Early Runner, and Florigiant at various intervals both before and after maturity was reached. He found no significant differences among cultivars in the estimated numbers of all fungi found on pod surfaces or in kernels in Georgia. A single community of fungi composed of the dominant genera *Penicillium* and *Aspergillus* was found associated with the geocarpoplane and geocarposphere. *Fusarium* was a common sub-dominant genus. The "geocarpoplane" and "geocarposphere" are terms developed by Garren (75) for the study of microorganisms associated with peanut pods. They are analogous to the terms

"rhizoplane" and "rhizosphere" in the study of roots. A succession of well-defined communities was not observed, though fluctuations in the densities of the dominant fungi did occur over sampling periods. Immature kernels from pods taken from the soil had an endocarpic community that was also dominated by species of *Aspergillus* and *Penicillium*. In the Argentine cultivar, *Chaetomium* sp. was co-dominant, while in the Early Runner and Florigiant, *Thielavia* sp. was a co-dominant species. *Fusarium* spp. were very common for all three cultivars throughout the period, while *R. solani* became prominent at maturity. The endocarpic community found on immature kernels was succeeded by a post-maturity community. This community was dominated by *Aspergillus* spp., *Penicillium* spp., *Sclerotium bataticola (Macrophomina phaseolina)*, and *Rhizopus* spp. The fungal community from shells (pods) in the soil was dominated by the species of *Fusarium* and *Penicillium,* while sub-dominants included *S. bataticola* and species of *Thielavia*, *Chaetomium*, and *Rhizoctonia*. In shells from the wind-row, *S. bataticola* and species of *Fusarium* and *Rhizopus* dominated while sub-dominants included *Rhizoctonia* spp., *Trichoderma* spp., *Nigrospora* spp., and *Curvularia* spp.. Jackson (99) found progressive changes in fungal associations; however, a succession of distinct communities was only found for the endocarpic fungi. The short duration of this study during the season may have impacted this.

Between 1965 and 1969, Hanlin (86) evaluated 4,469 fungal isolates collected from peanut pods and seeds. The isolates were collected in six states including Georgia, North Carolina, Oklahoma, Alabama, Texas, and Virginia.

While no attempt was made to quantify the relative abundance of fungal types, Hanlin (85) identified 70 genera and 146 species of fungi. Nine of the genera were Oomycetes and Zygomycetes, 17 were Ascomycetes, and 44 were Deuteromycetes. In a survey of fungi associated with peg and pod rot in South Carolina, Hotchkiss and Baxter (97) identified a number of fungi, including *Fusarium* spp., *Penicillium* spp., *Calonectria crotalariae (Calonectria illicicola)*, *Trichoderma* spp., *Neocosmospora vasinfecta*, *Rhizopus* spp., and *Aspergillus* spp. *Sclerotium rolfsii* and *R. solani* were also isolated, but with less frequency than the others. Baird et al. (12, 13, 14) evaluated the mycoflora associated with peanut pods in relation to several variables, including peanut variety, harvest date, chemical treatment, crop rotation, and isolation medium. Throughout the study, more that 31 genera were identified. The most common genera included *Alternaria*, *Fusarium*, *Curvularia*, *Lasiodiplodia*, *Nigrospora*, *Rhizoctonia*, *Rhizopus*, *Mucor*, *Phoma*, and *Trichoderma*.

Fungi associated with other crops, that included landino clover, corn, and wheat, have been studied and described (38, 62, 185). Dawson and Bateman (62) isolated 41 genera of fungi from the roots of winter barley and winter wheat grown in Great Britain. The most common genera included *Alternaria, Cladosporium, Cylindrocarpon, Fusarium, Idriella, Absidia, Mortierella, Mucor, Penicillium, Phoma, Trichoderma,* and *Verticillium.* Young and Kucharek (185) identified five communities of fungi associated with the growth of corn in Florida. Some of the more common fungi included *Pyrenochaeta terrestris, Fusarium solani, Rhizopus* spp., *Penicillium spp., Fusarium moniliforme, Trichoderma*

viride, Curvularia sp., Mortierella sp., M. phaseolina, R. solani, S. rolfsii, Drechslera rostrata, and *Diplodia maydis*. In soybean, Mueller et al. (126) found species of *Chaetomium, Fusarium, Gliocladium, Penicillium, Trichoderma, Phomopsis*, and *Macrophomina* commonly associated with the roots.

Complexes of Soilborne Fungi

A group of soilborne pathogens may be involved in the diseases of root systems, and root-rots may be the result of several pathogens, both major and minor, involved in a complex interaction. For example, *R. solani* was found to infect the juvenile tissues of young wheat seedlings in Australia, but was not easily isolated from mature plants beyond the tillering stage (88). However, the early infection by *R. solani* increased the severity of the root-rot caused by secondary pathogens such as *Fusarium equiseti, F. avenaceum, Cochliobolus sativus, Microdochium bolleyi*, and *Alternaria alternata*. Though *R. solani* was not the direct cause of root-rot of wheat, it was important in predisposing the plants to infection by other fungi. A second example that involves a complex of soilborne fungi is the sudden wilt disease of melon, *Cucumis pepo* L., which primarily affects plants in arid and semi-arid regions of the world (140). Sudden wilt disease is caused in part by a group of pathogens that includes *Monosporascus* sp., *Pythium apanidermatum, F. solani*, and *R. solani*. Red root rot of corn is caused by a complex of pathogens that include *Phoma terrestris, Pythium irregulare*, and *Fusarium acuminatum* (119). Mao et al. (119) found that *P. terresstris* and *P. irregulare* are the major components of this disease, and that *F. acuminatum* is of secondary importance.

Pod rot of peanut has been attributed to a complex of pathogens that includes *F. solani*, *P. myriotylum*, and *R. solani* (71, 76). Garcia and Mitchell (74) evaluated the interactions of *P. myriotylum* with *R. solani*, *M. phaseolina*, *F. solani*, and *T. viride* in the development of pod rot. *Rhizoctonia solani* had an antagonistic affect on pod rot caused by *P. myriotylum*, though high populations of *M. phaseolina* could nullify this effect. Exposure of pods to *F. solani* or *T. viride* prior to exposure to *P. myriotylum* or *R. solani* did not inhibit pod rot, but did greatly reduce the isolation of *P. myriotylum* and *R. solani* from the diseased pods. Garcia and Mitchell (73) also found that peanut pod rot was more severe when pods were grown in soil that contained combinations of *P. myriotylum* and *F. solani* or the nematode *Meloidogyne hapla* than it was in soil with only one of these pathogens.

The severity of disease caused by soilborne fungal pathogens may be increased in the presence of plant parasitic nematodes (1, 94, 128, 173). Examples include Fusarium wilt of cotton, black shank of tobacco, Verticillium wilt of strawberries, Rhizoctonia seedling disease in soybean, and charcoal rot of sorghum. Hasan (89) found that the severity of root disease caused by either *P. aphanidermatum* or *R. solani* on chrysanthemum was greater in the presence of the lesion nematode *Pratylenchus coffeae*. Culbreath et al. (59) and Diomande and Beute (64) evaluated the impact of the plant parasitic nematodes *Meloidogyne hapla, M. arenaria,* and *Macroposthonia ornata* on the development of Cylindrocladium black rot in peanut. In a pot experiment, Diomande and Beute (64) found that *M. hapla* increased disease severity on the peanut

varieties 'NC 3033' and 'Florigiant.' The severity of Cylindrocladium black rot was increased on Florigiant in the presence of *Macroposthonia ornata*; however the disease severity in NC 3033 was not increased by this nematode. In microplot studies, Culbreath et al. (59) found that *M. arenaria* and *M. hapla* increased the severity of Cylindrocladium black rot in the peanut varieties Florigiant, NC 10C, NC Ac 18416, NC Ac 18016. Bell et al. (17) found that damage to peanut pods by *M. arenaria* did not increase infection by *A. flavus*. Porter and Smith (144) also found that feeding damage caused by the rootworm larvae, *Diabrotica undecimpunctata howardi*, did not increase colonization by *A. flavus*, but did increase pod rot in association with *P. myriotylum*.

Environmental Influences on Soilborne Diseases

The most important environmental factors that affect disease development are temperature and moisture. Boyle (28) found that excessive heating of peanut seedlings at the soil surface resulted in the formation of "heat cankers." Collar rot frequently followed the formation of the cankers and it was hypothesized that these wounds provided entry for weakly pathogenic organisms. Phipps and Beute (137) found that a soil temperature of 25° C and a moisture content near field capacity were most conducive for infection and rot of peanut roots by *Cylindrocladium crotalariae* (*Cylindrocladium parasiticum*). Root infection and rot were reduced at soil temperatures of 20° C and 30° C, while no measurable disease was noted for plants at 35° C. Also, less disease developed at 20° C, 25° C, and 30° C when the plants were irrigated only as the soil moisture content reached the near-wilting point of the plants. The survival of

microsclerotia was not affected by either the soil temperature or the irrigation regime. Sidebottom and Beute (156) attempted to control Cylindrocladium black rot using cultural practices that would modify soil temperature. Disease incidence was reduced when planting was delayed for up to 4 weeks beyond the recommended planting date. Soil temperatures were higher when planting was delayed; however there was no significant increase in yield. During the first year of this study, disease incidence was reduced when the peanut seed was planted in beds rather than in flat rows. Shew and Beute (154) found that the incidence of southern stem rot caused by *S. rolfsii* was greatest when there was abundant inoculum, adequate moisture, and when defoliating pests were controlled. Porter et al. (145) found that, in Virginia, the incidence and severity of Sclerotinia blight caused by *Sclerotinia minor*, pod rot caused by *S. minor* and *P. myriotylum*, and early leafspot, caused by *Cercospora arachidicola*, increased with the use of sprinkler irrigation. Stewart et al. (165) reported that the relationship between prevailing climatic conditions and plant phenology was more important to the incidence *A. flavus* and levels of aflatoxin than was row spacing.

The effect of temperature on disease development has also been researched for other pathosystems (40,166). Subbarao and Michailides (166) found that the relative importance of two diseases of fig, endosepsis, caused by *F. moniliforme*, and smut, caused by *A. niger*, was dependent on ambient temperature. At temperatures of 30° C and 35° C, the rate of lesion expansion for *A. niger* was twice the rate for *F. moniliforme*. At temperatures less than 25° C, lesions caused by *F. moniliforme* isolates were larger than were those for *A.*

niger. Carling and Leiner (40) found that isolates of anastomosis group 3 (AG-3) of *R. solani* heavily damaged potato sprouts at 10°, 15.5°, and 21.1° C, but caused significantly more damage at 10° C. Isolates of AG-5 also damaged roots at all three temperatures. Isolates of AG-5 of *R. solani* damaged sprouts at 15.5° and 21.1° C, but caused only minimum damage to the roots. Isolates of AG-8 caused damage to roots, but only minor damage to sprouts at all temperatures. Therefore, at cooler temperatures it seemed that isolates of AG-3 were more virulent, while at warmer temperatures isolates of AG-5 and AG-8 may be more important in Rhizoctonia diseases of potato.

Cultivation Practices and Rotation in Soilborne Disease in Peanut

Survival and spread of soilborne inoculum is affected by cultural practices, such as crop rotation and the movement of equipment within fields. Soil samples were taken from peanut-cultivation equipment at the time of use in three peanut fields in Virginia with histories of Cylindrocladium black rot (109). Microsclerotia of *Cylindrocladium crotalariae* (*C. parasiticum*) were found in 52 of 59 samples. The researchers also found that the movement of infested soil in drainage waters might be a means of pathogen dispersal. Griffin et al. (83) found that rotation of peanut behind corn was associated with increased soil populations of *A. flavus*. This same increase was not observed when peanuts were planted after fallow, peanut, soybean, or sorghum-sudangrass. Sidebottom and Beute (157) found that the fastest rate of increase in severity of Cylindrocladium black rot occurred when either corn or soybean was followed by 2 years of peanut. Interestingly, continuous monoculture of peanut for 3 years led to only a moderate rate of

increase and low incidence of Cylindrocladium black rot. The density of microsclerotia was lower after corn than after either peanut or soybean. Black and Beute (23) found that inoculum densities of microsclerotia were greater when soybean or the susceptible peanut variety Florigiant were planted as compared to the more resistant variety NC 3033 or corn, a non-host. However, the efficiency of the microsclerotia to induce peanut root rot was greatest following NC 3033, intermediate following Florigiant, and low following soybean.

Minton et al. (125) found that there was less damage to peanut from *S. rolfsii* and *R. solani* in a wheat-peanut cropping system than in a fallow-peanut system. Bowen et al. (27) found that peanut yield was inversely related to the incidence of southern stem rot, and that the incidence of southern stem rot was inversely related to the number of years between peanut crops.

Use of Fungicides in the Control of Soilborne Disease in Peanut

In the southeastern United States, fungicides are used to control soilborne diseases of peanut. One important fungicide is flutolanil, which is sold under the trade name "Moncut." The active ingredient in flutolanil is N- (3-(1-methylethoxy) phenyl)-2-(trifluoromethyl) benzamide. Flutolanil is a systemic fungicide and is formulated as a wettable powder. In peanut production, flutolanil has been used successfully to control Rhizoctonia limb rot (16, 125). It has also been used successfully to control southern stem blight (30, 60, 70, 112, 125).

A second important fungicide is tebuconazole that is marketed under the name of Folicur. The active ingredient in tebuconazole is α-(2-[4-chlorophenyl]-ethyl)-α-(1,1-dimethylethyl)-1H-1,2,4-triazole-1-ethanol. Tebuconazole is a

systemic fungicide and is used in the control of foliar diseases of peanut in addition to southern stem blight (32, 33, 70, 148). Tebuconazole has also been found to be effective against Rhizoctonia limb rot (33).

The insecticide chlorpyrifos (Lorsban 15G) was also found to have activity against southern stem blight (52, 113). Kucharek and Edmondson (113) found that chlorpyrifos reduced the severity of southern stem rot by suppression of fungal growth. Csinos (52) found that the chlorpyrifos hydrolysis product, 3,5,6-trichloro-2-pyridinol, was more effective in reducing the radial growth of *S. rolfsii* than were the technical, 15G, or 4EC formulations of the product.

Influence of Crop Development on Fungal Infection

Ecological Competition in Fungal Infections

The use of ecological concepts may offer a further understanding of the species-specific infection periods found in some cropping systems. In the context of general ecology, two basic life history strategies are presented. The r-selected fungal species are the initial colonizers of a new habitat and rapidly use simple sugars as a source of nutrition (120). In general, the r-selected species tend to be short-lived and use much of their resources in the production of many offspring (117). Fungal communities that are initially found in the new habitat usually have a low diversity and most of the members will be r-selected organisms (121). K-selected species, however, utilize more complex nutrient sources, live longer, and use fewer resources in the production of offspring (117, 120). In the more diverse communities which develop later, r-selected species are less fit to compete for resources and are replaced by a larger diversity of K-

selected species (121). Lockwood (117) describes *R. solani*, which lacks asexual spores but which can persist in the soil for long periods of time as being relatively K-selected. He considers pathogens such as *Pythium* spp. and *Phytophthora* spp. to be less K-selected and more r-selected, because they frequently produce sexual and asexual spores. Foliar pathogens, for example the rust fungi, are considered to be even more r-selected. Marois and Coleman (120) present *Botrytis cinerea* and *Armillaria mellea* as examples of r- and K-selected species, respectively. The concepts of the r- and K-selected species and ecological succession, defined as a replacement of populations in a habitat through a regular progression to a steady state, could be important in the progress of infection periods which appears to occur in peanut.

Successions of fungal communities have been reported in the literature. Examples include studies on the succession of seed-borne fungi of rice beginning at flowering (115), the succession of plant pathogens in natural populations of three plant species (42) and fungal succession on tomato after soil fumigation (121).

Pathogens Important Early in Host Development

The literature contains a number of studies that describe the relationship between the age of a host plant and the severity of the symptoms developing in a diseased individual. In many cases, the age of the host at the time of artificial inoculation or exposure to the pathogen is an important factor in the progress of the disease. In some examples, it is the younger plants that are most affected by the pathogen. Researchers who studied Stewart's and Goss's bacterial wilt of

sweet corn found that the growth stage at the time of inoculation influenced the severity of disease symptoms (168). When corn plants at the three- to five-leaf stage were inoculated with *Erwinia stewartii* and *Clavibacter michiganense* subsp. *nebraskense*, disease symptoms were greater than for those plants inoculated at the five- to seven-leaf or seven- to nine-leaf stage. Damping-off of seedlings and crown rot of sugar beet (*Beta vulgaris* L.) is caused by *Rhizoctonia solani* Kuhn AG 2-2. Researchers found that root rot ratings were greatest for plants inoculated at 6 weeks of age and decreased as the age of the plant at the time of inoculation increased from 8 to 10 to 12 weeks (66). Seed rot and preemergence damping-off of chickpea (*Cicer arietinum* L.) is caused by *Pythium ultimum* Trow. When seeds of chickpea were planted in a greenhouse potting mixture or field soil infested at either 50 or 500 cfu/g, there was a complete lack of seedling emergence. However, when 10-day-old seedlings were transplanted into both types of soil with the same inoculum levels, the plants did not develop disease symptoms and grew similarly to those of the control (177). Wheat, cv. Warigal, grown in Australia was infected at an early age with *R. solani*. However, at later growth stages, this pathogen could no longer be isolated from the tissue and had been replaced by a number of other pathogens (88). Finally, in at least some attempts to breed for disease resistance, the susceptibility of the host based upon crop age has been an important consideration. For example, soybean (*Glycine max*) is afflicted by a stem canker disease that is caused by *Diaporthe phaseolorum* (Cke. and Ell.) Sacc. var. *caulivora*. In a breeding study, different varieties were inoculated when the plants were 30- and 60-days old.

Varieties that showed no difference in disease symptoms 70 days after inoculation were considered resistant. A variety was considered moderately resistant if the plants inoculated at a younger age had less severe symptoms than plants inoculated at the older age. Finally, varieties were considered to be nonresistant if greater mortality occurred in the younger plants than in the older plants (103).

Pathogens Important in Later Host Development

Examples also exist where it appears that some crops are more susceptible to diseases caused by specific pathogens later in the growing season rather than earlier. In soybean, the developing pods are known to be the pathway for infection of the seeds by the pathogens *Phomopsis longicolla* Hobbs sp. nov., *Diaporthe phaseolorum* (Cke. And Ell.) Sacc. var. *sojae*, and *D. phaseolorum* var. *caulivora*. Though the pods may be infected as early as the time of flowering, most of the infection of the seeds does not occur until the R7, or beginning maturity growth stage. Researchers have also found that infection of the seed appears to be greater at the R7 than at the R8 growth stage (15). Sudden death syndrome of soybean seems to be caused by the pathogen *Fusarium solani*. In research studies, the severity of sudden death syndrome seems to increase during reproductive development in the host, especially during the R2-R5 growth stages (149). This rapid increase in symptoms may be related to an accumulation of heat units during warm days and changes in the plant physiology associated with reproductive development. Finally, Gwinn et al. (84) studied the relationship between infection of three corn cultivars with different

resistance levels to the foliar pathogen *Cercospora zea-maydis* and the age of the host. In their research, at least part of the resistance in the different cultivars can be explained by the ability of *C. zea-maydis* to penetrate the leaf stomata. At 1 and 2 months of age, there is little difference in the amount of penetration by fungal hyphae among the three cultivars. However, at 3 months of age, the level of penetration was greatest in the susceptible variety, less in the tolerant variety, and lowest in the resistant variety. Research has also shown that Fusarium wilt, caused by *Fusarium oxysporum* f. sp. *tracheiphilum*, of cowpea (*Vigna unguiculata*) can be more severe when older plants are inoculated than when younger plants are inoculated (169). These researchers found that there were significantly higher vascular discoloration ratings when plants were 20 days old at the time of inoculation rather than 12 days old. In some instances, older plants were more likely to be killed by the pathogen than were younger plants.

Pathogens Important Throughout Host Development

In the previous examples, disease severity in certain crops appears to be related to the age of the plant at the time of infection, or at the time when symptoms first appear. In some pathosystems, there seems to be little relationship between the host age and the progress of the disease. Fritz et al. (72) determined that there was no consistent relationship between the age at the time of infection of Chinese cabbage (*Brassica campestris* Group *pekinensis*) by *Erwinia carotovora* ssp. *carotovora* and the progress of soft rot development. Researchers have suggested that the susceptibility of chickpea (*Cicer arietinum*) to Ascochyta blight caused by *Ascochyta rabiei* (Pass.) Labr. increases with age.

In a recent study, Trapero-Casas and Kaiser (176) demonstrated that 2-week-old seedlings and 8-week-old plants are similarly affected when one compares the maximum disease severity for each age group. Similar results were obtained when chrysanthemum (*C. morifolium* Ramat)-rooted cuttings were inoculated with *Verticillium dahliae* on a weekly basis for 4 weeks. No increase in disease severity due to vascular wilt was found with increasing age at the time of inoculation (135). Finally, young sunflower plants (*Helianthus annuus*) ranging in age from 1 to 21 days old were equally susceptible to a seedling blight caused by *Alternaria helianthi* (101).

CHAPTER 3
SOILBORNE FUNGI ISOLATED FROM PEANUT PLANTS

Introduction

Peanut, *Arachis hypogaea* L., was grown on approximately 39,660 hectares in Florida in 1998, with a total yield valued at more than $57 million (6). Peanut is grown primarily in the northern and panhandle regions of the state. It ranks among the 20 most valuable agricultural commodities produced in Florida and among the three most important agronomic crops.

Because the fruit (pods) of the peanut plant develop in the soil, the crop is particularly susceptible to diseases caused by soilborne fungal pathogens. Soilborne fungi infect the roots, the hypocotyl, the pods, and the gynophores (pegs) that attach the pods to the limbs of the plant. Important soilborne fungal pathogens of peanut in Florida include *Athelia rolfsii* (Curzi) Tu & Kimbrough (anamorph=*Sclerotium rolfsii* Sacc.), *Thanatephorus cucumeris* (A.B. Frank) Donk (anamorph=*Rhizoctonia solani* Kuhn), *Calonectria ilicicola* Boedijn & Reitsma (*Cylindrocladium parasiticum* Crous *et al.*), *Aspergillus niger* Tiegh, *Lasiodiplodia theobromae* (Pat.) Griffon & Maubl., and *Pythium myriotylum* Drechs. *Aspergillus flavus* Link :Fr is important in peanut production because of its potential to produce aflatoxins in the peanut kernels.

The mycoflora associated with peanut pods has been assessed in a number of studies (12, 13, 14, 75, 86, 95, 97, 99). In most of these studies, the

researchers were primarily interested in the fungi from mature peanut pods harvested in the southeastern United States, though one study followed the progression of fungi on the pods beginning 45 days prior to harvest (99). In another study, 70 genera and 146 species of fungi were isolated from peanut shells and peanut fruit (86). Common genera isolated from randomly selected pods included *Alternaria, Curvularia, Fusarium, Lasiodiplodia, Mucor, Nigrospora, Phoma, Rhizoctonia, Rhizopus,* and *Trichoderma* (12, 14). In other studies, fungi commonly isolated from rotted pods include *Fusarium* spp., *Penicillium* spp., *C. parasiticum, Trichoderma* spp., *Neocosmospora vasinfecta, Rhizopus* spp., *Aspergillus* spp., *S. rolfsii, Pythium* spp., and *R. solani* (95, 97).

The inventories of fungi described above were limited primarily to the peanut pods. The research presented here is the first work to describe the fungi that can be isolated not only from the pods, but from the roots, hypocotyl and pegs of the host as well. This will provide a more complete characterization of the soilborne fungi associated with peanut production. Since diseases of the roots and pods are important in peanut production in Florida, such information will be useful to develop control tactics.

There were three objectives in this research. The first was to inventory the fungi associated with the underground portions of the peanut plant and to determine their diversity and abundance. The second objective was to test the pathogenicity of fungi that were commonly isolated. This would provide a means to rank the relative virulence of different fungi and to identify weaker, lesser-known pathogens that may have an impact on the health of the peanut plant.

The third objective was to evaluate, *in vitro*, potential antagonistic competition between pathogenic fungi and other commonly isolated fungi. This was to provide evidence of natural biological control that might occur in this specific agricultural ecosystem. Evidence of naturally occurring biological control agents would be further evidence for the cautious use of broad-spectrum fungicides that might reduce populations of beneficial fungi.

Materials and Methods

Survey of Fields

To characterize the fungi associated with the roots, hypocotyl, pods, and pegs of peanut grown in Florida, a survey of commercial fields was conducted across the peanut production areas of Florida. This survey covered the entire growing seasons of 1995 and 1996. The survey was conducted primarily in commercial fields, but samples were also collected from experimental field plots in each season. Samples were collected from 28 sites.

Site Selection

Commercial fields were selected for intensive sampling based on several criteria. First, the fields were selected to survey the most important production regions in the state. These fields were located in Santa Rosa, Jackson, Suwannee, Levy, and Columbia Counties. The location of these counties is presented in Figure 3-1. The second consideration was grower cooperation. County extension agents were asked to identify growers who would cooperate with the research. Such cooperation included permission to sample and remove plants from a field throughout the growing season and to share records of

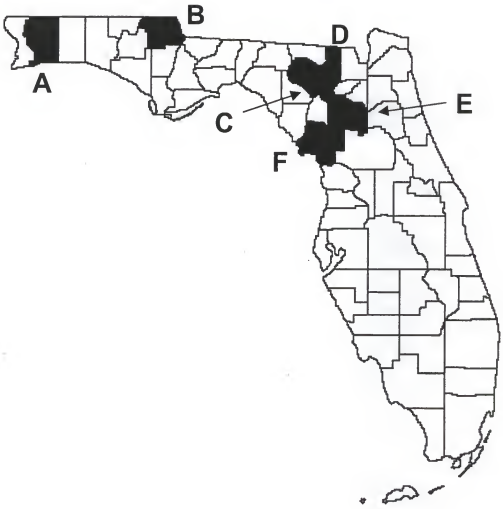


Figure 3-1. Counties in Florida where peanut plants were sampled during 1995 and 1996. A. Santa Rosa County. B. Jackson County. C. Suwannee County. D. Columbia County. E. Alachua County. F. Levy County.

fungicide applications and crop rotation. Finally, consideration was given to fields known to have had a high or low incidence of soilborne diseases in the past. Experimental plots were selected in cooperation with researchers at experiment stations in the state where work on peanut was being conducted. Tables 3-1 and 3-2 contain summaries of the soil types, cropping histories, and cultivars planted in fields from 1995 and 1996. Table 3-3 contains a summary of fungicide programs and yield information for the same sites.

Sampling Techniques

Plants were destructively sampled from selected sites throughout the growing season. Sites were sequentially sampled five times over the season beginning approximately 2 weeks after planting. The interval between sampling trips was normally 3 weeks. This interval varied because distances between sampling sites and the time required to process samples. Twenty plants were destructively sampled from each site per sampling trip. A systematic sampling scheme was selected based upon work done by Hau, Campbell, and Beute (91). The pattern used for sampling was composed of four transects linked in the shape of the letter "W." The length of each transect was determined by the size of the field. The length of the transects was maximized to cover as much of a given field as was reasonably possible. Plants were sampled based upon a predetermined position along a transect and without regard to the presence or absence of symptoms of disease. The transects covered similar, but not identical, areas of the field on each sampling date. Individual plants were dug from the soil to preserve a substantial portion of the root system and pods.

Table 3-1. Characteristics and cultural information collected from fields of peanut (*Arachis hypogaea* L.) in Florida in 1995.

Field	County	Type[x]	Soil type[y]	pH	Area (ha)	Cultivar	Crop history (1993-1994)	Planting date
101	Levy	C	OT	6.1	46	Florunner	4 yr Bahia grass	Mar 27
102	Levy	C	JOS	4.9	4	Valencia	1994-peanut	Feb 15
103	Levy	C	OFS	5.3	40	Sunrunner	13 yr Bahia grass	Apr 19
104	Columbia	R	BFS	5.3	9	Florunner	peanut-tobacco	May 18
105	Suwannee	C	BFS	5.8	24	SunOleic 95R	15 yr Bahia grass	Apr 4
106	Suwannee	C	BFS	5.6	14	SunOleic 95R	2 yr fallow (peanut 1992)	Apr 5
107	Suwannee	C	BFS	5.4	10	GK-7	fallow/rye-corn	Apr 17
108	Suwannee	C	BFS	5.1	10	Andru 93	peanut-rye/millet	Apr 3
109	Suwannee	C	BFS	6.5	44	NCV 11	peanut[z]-corn	May 25
110	Alachua	R	AFS	5.7	N/A	Florunner	Bahia grass-soybean	May 1
111	Suwannee	R	BFS	5.8	N/A	Florunner		Apr 27
112	Jackson	C	DLS	5.5	20	Andru 93	corn-corn	Apr 27
113	Jackson	C	DLS	5.3	14	Florunner	soybean&wheat-cotton (peanut 1992)	Apr 27
115	Jackson	C	FCS	5.5	40	Florunner	peanut-corn	Apr 15
116	Santa Rosa	C	RBSL	5.8	4	GK-7	cotton-cotton	May 4
117	Santa Rosa	C	RBSL	5.9	0.8	GK-7	cotton-cotton	Apr 25
118	Santa Rosa	C	RBSCL	5.8	16	GK-7	corn-cotton	Apr 17
119	Jackson	C	DLS	6.1	0.8	Andru 93	corn-corn	May 13

[x] C = commercial field; R = experimental site.

[y] OT = Otela-Tavares Complex; JOS = Jonesville-Otela-Seaboard Complex; OFS = Orlando Fine Sand; BFS = Blanton Fine Sand; AFS = Arredondo Fine Sand; FCS = Fuquay Coarse Sand; RBSL = Red Bay Sandy Loam; RBSCL = Red Bay Sandy Clay Loam; CFS = Candler Fine Sand; BS = Bonifay Sand; DLS = Dothan Loamy Sand.

[z] Peanuts were preceded in spring by potato crop.

Table 3-2. Characteristics and cultural information collected from fields of peanut (*Arachis hypogaea* L.) in Florida in 1996.

Field	County	Type[w]	Soil type[x]	pH	Area (ha)	Cultivar	Crop history (1993-1994)	Planting date
201	Levy	C	CFS	6.8	61	Florunner	5 yr Bahia grass	Apr 5
202	Suwannee	C	BFS	5.9	7	Georgia Runner	watermelon-peanut	Apr 22[y]
203	Suwannee	C	BFS	6.4	10	Georgia Runner	millet & rye-millet & oats	May 1
204	Suwannee	C	BFS	6.4	55	NCV-11	peanut[z]-cucumber& sweet corn	
206	Alachua	R	AFS	6.5	FP	Florunner	3 yr Bahia grass	
207	Alachua	R	AFS	6.4	FP	Florunner	3 yr Bahia grass	
208	Alachua	R	AFS	6.2	FP	Florunner	Bahia grass-peanut	
209	Jackson	C	BS	6.4	26	GK-7	cotton-cotton	Apr 27
211	Jackson	C	BS	5.4	16	GK-7	peanut-corn	May 9
212	Santa Rosa	C	RBSL	6.2	10	GK-7	cotton-cotton	May 10
213	Santa Rosa	C	RBSL	6.3	10	GK-7	cotton-cotton	Apr 20
214	Santa Rosa	C	RBSCL	6.3	73	GK-7	cotton-cotton	Apr 15

[w] C = commercial field; R = experimental site.

[x] OT = Otela-Tavares Complex; JOS = Jonesville-Otela-Seaboard Complex; OFS = Orlando Fine Sand; BFS = Blanton Fine Sand; AFS = Arredondo Fine Sand; FCS = Fuquay Coarse Sand; RBSL = Red Bay Sandy Loam; RBSCL = Red Bay Sandy Clay Loam; CFS = Candler Fine Sand; BS = Bonifay Sand; DLS = Dothan Loamy Sand.

[y] Some parts of field replanted on May 6. [§] Peanut preceded in spring by potato crop.

[z] Peanuts were preceded in spring by potato crop.

Table 3-3. Yields and fungicide information collected from commercial fields of peanut (*Arachis hypogaea* L.) in Florida in 1995 and 1996.

Field	Harvest	Yield kg ha^{-1}	Grade	Irrigated	Gypsum	Fungicide applications
101[v]	15 Aug 95	6132	N/A[w]	Yes	18 May	1xtebuconazole 1xManzate 6xManzate/sulfur
102	No harvest	N/A	N/A	No	No	N/A
103	Early Sep 95	4942	74	No	12 Jun	5xchlorothalonil 2xsulfur 1xtebuconazole 1xbenomyl 1xchlorpyrifos
104[x]	22 Sep 95	N/A	N/A	No	N/A	+/- [y] Telone II+chlorothalonil
105	21 Aug 95	3497	77.4	No	20 May	5xchlorothalonil 1xsulfur
106	21 Aug 95	3221	76.5	No	19 May	5xchlorothalonil 1xsulfur 1xtebuconazole
107	20 Sep 95	2900	77	No	6 Jun	2xchlorothalonil 4xtebuconazole 1xbenomyl+chlorothalonil
108	7 Sep 95	1950	70	No	6 Jun	1xbenomyl 1xbenomyl+chlorothalonil 2xchlorothalonil 1xtebuconazole 3xchlorpyrifos
109	14 Oct 95	3746	73.6	Yes	Yes[z]	2xchlorothalonil 1xsulfur 5xtebuconazole 1xchlopyrifos
110[x]	11 Sep 95	N/A	N/A	Yes	Yes	(+/- tebuconazole or chlorpyrifos), chlorothalonil
111[x]	27 Aug 95	N/A	N/A	No	No	+/- Telone II,+ chlorothalonil
112	5 Oct 95	4460	65 - 72	No	1 Jul	1xtebuconazole+benomyl 2xtebuconazole+chlorothalonil 2xchlorothalonil
113	27 Sep 95	2807	69 - 73	No	14 Jun	3xchlorothalonil 1xbenomyl 2xtebuconazole+chlorothalonil
114	Not studied	N/A	N/A	N/A	N/A	
115	Sep 95	4341	72 - 78	No	16 Jun	1xchlorothalonil 1xbenomyl 3xtebuconazole

Table 3-3 continued.

Field	Harvest	Yield kg ha^{-1}	Grade	Irrigated	Gypsum	Fungicide applications
116	15 Sep 95	3000	70	No	15 Jun	2xchlorothalonil 4xtebuconazole
117	5 Sep 95	3500	69	No	10 Jun	2xchlorothalonil 4xtebuconazole
118	Aug 95	4559	68 - 75	No	Yes	1xchlorothalonil 4xtebuconazole+chlorothalonil
119	5 Oct 95	Treated with Field 112				
201	Aug 96	5554	N/A	Yes	23 May	1xManzate 6xManzate + sulfur 1xtebuconazole+chlorothalonil
202	27 Sep 96	2800	72	No	30 Jun	1xchlorothalonil 1xtebuconazole+chlorothalonil 2xflutolanil+chlorothalonil + sulfur 1xflutolanil+chlorothalonil
203	23 Sep 96	3000	70 - 71	No	30 Jun	1xbenomyl 2xchlorothalonil 3xtebuconazole+chlorothalonil 1xsulfur
204	Oct 96	3174	67	Yes	Jul	1xbenomyl 9xtebuconazole
205	Not studied	N/A	N/A	N/A	N/A	
206[x]	19 Sep 96	N/A	N/A	Yes	Yes	(+/- tebuconazole or chlorpyrifos), chlorothalonil
207[x]	19 Sep 96	N/A	N/A	Yes	Yes	Chlorothalonil
208[x]	19 Sep 96	N/A	N/A	Yes	Yes	Chlorothalonil
209	19 Sep 96	2783	71	No	None	3xchlorothalonil 4xtebuconazole
210	Not studied	N/A	N/A	N/A	N/A	
211	Sep 96	4000	71	No	pegging	2xchlorothalonil 4xtebuconazole+chlorothalonil
212	Sep 96	4200	74	No	N/A	N/A
213	Aug 96	3270	N/A	No	N/A	N/A
214	Sep 96	5126	73 - 78	No	27 May	5xtebuconazole+chlorothalonil + sulfur, 1xchlorothalonil

[v] See Table 3-1 and 3-2 for the locations of these fields. [w] N/A: this information was unavailable from the grower. [x] These were experimental sites rather than commercial fields.
[y] "+/-" indicates experimental plots where compounds were added to some, but not to all plots.
[z] "Yes": gypsum was applied at pegging; however, the date was unavailable from the grower.

Excess foliage was removed before returning to the laboratory. At sites where experimental plots were established, either two or three plants were arbitrarily sampled from each plot. Immediately after the plants were sampled, they were placed in plastic bags and put in ice coolers. The total number of plants sampled from each site is presented in Table 3-4.

Laboratory Preparation

Upon return to the laboratory, plant samples were refrigerated until they could be processed, normally, within 3 days. Samples were washed with tap water to remove soil from the root systems, pegs, and pods. After washing, the growth stage of each plant was determined using a scheme developed by Boote (25). A summary of this scheme is presented in Table 3-5. Each plant then received a health rating based upon a scale of 1-10, where plants with a rating of "1" appeared disease free. A summary of the rating scale is presented in Table 3-6. Each plant was washed with tap water again and then sectioned into four distinct regions: the hypocotyls, roots, pods, and pegs. Even though the hypocotyls became morphologically identical to the taproot as the plant matured, they were distinguished from the roots throughout the study based upon their position on the plant. After the sectioning was completed, the pieces were placed into the compartments of sterilization boxes, such as the one pictured in Figure 3-2. The pieces were then surface sterilized by submerging the entire box in a tub containing a solution of 0.525% sodium hypochlorite made by adding one part commercial bleach to nine parts tap water. Ten drops of the surfactant Triton-X were added per liter of solution to obtain complete coverage

Table 3-4. Number of plants evaluated from each site during sampling phase of peanut fungal survey.

1995		1996	
Field	No. of plants	Field	No. of plants
101[z]	95	201	100
102	80	202	100
103	95	203	100
104	112	204	100
105	95	206	150
106	95	207	120
107	94	208	102
108	81	209	100
109	95	211	100
110	116	212	100
111	100	213	80
112	90	214	100
113	89		
115	90		
116	90		
117	90		
118	90		
119	70		
Total	1587		1270

[z] The location of these fields is presented in Tables 3-1 and 3-2.

Table 3-5. Growth stages of peanut[z]

Stage	Abbreviated stage title	Description
		Vegetative stages
VE	Emergence	Cotyledons are near the soil surface with seedling showing some part of the plant visible.
V0		Cotyledons are flat and open at or below the soil surface.
V1..V(n) . .	First to *n*th tetrafoliate	1 to n developed nodes are on the main axis; a node is counted when its tetrafoliate is unfolded and its leaflets are flat.
		Reproductive stages
R1	Beginning bloom	One open flower is at any node on the plant.
R2	Beginning peg	One elongated peg (gynophore) is present.
R3	Beginning pod	One peg is in the soil with turned, swollen ovary at least twice the width of the peg.
R4	Full pod	One pod is fully expanded, to dimensions characteristic of the cultivar.
R5	Beginning seed	One fully expanded pod in which seed cotyledon growth is visible when the fruit is cut in cross section with a razor blade (past the liquid endosperm phase).
R6	Full seed	There is a least one pod with cavity apparently filled by the seeds when fresh.
R7	Beginning maturity	There is at least one pod showing visible natural coloration or blotching of inner pericarp or testa.
R8	Harvest maturity	Two-thirds to three-fourths of all developed pods have testa or pericarp coloration. Fraction is cultivar-dependent, and lower for Virginia types than runner types.
R9	Overmature pod	One undamaged pod shows orange-tan coloration of the testa and/or natural peg deterioration.

[z] For population of plants, V stages may be averaged. Reproductive stages should not be averaged. An R stage should remain unchanged until the date when 50% of the plants in the sample demonstrate the desired trait of the next R stage. The timing of a reproductive stage for a given plant is set by the first occurrence of the specific trait on the plant without regard to position on the plant.

Source: Adapted from Boote (25).

Table 3-6. Numeric scheme to evaluate peanut plant health at the time of processing[z].

Evaluation	Description of condition
1	Peanut plant was healthy and lacked any disease symptoms.
2	Peanut plant was basically healthy, minor discoloration could occur.
3	Initial formation of lesions, only slightly more severe than discoloration.
4	Definite lesions were observed but were restricted in growth.
5	Definite lesions were observed with initial spread to other areas.
6	Severe lesions were present though somewhat restricted in scope, some wilt.
7	Severe lesions were becoming necrotic and plants were wilted.
8	Plant lesions were necrotic with substantial wilt.
9	Plant was severely diseased, necrotic lesions were present on multiple parts, severe wilt.
10	Plant was dead with massive necrosis.

[z] Evaluations were for the parts of the plant that occurred below the soil line and included roots, hypocotyls, pegs, and pods.

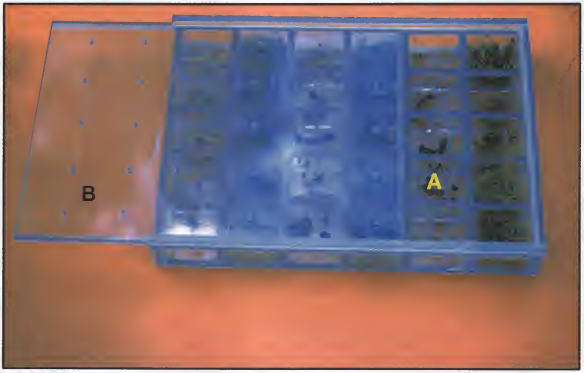


Figure 3-2. Surface sterilization box. Cut hypocotyls, roots, pegs, and pods were placed into cells (A) of this box, submerged in solutions of 0.5% hypochlorite, and then rinsed in sterilized water. The solution and water flowed into a cell through a small hole that was drilled into the lid above it (B). Air bubbles escaped through holes that were drilled on the other surface. Solution was also drained through these holes when the box was turned upside down.

of the plant parts by the solution of sodium hypochlorite. The sterilization box was submerged for 90 seconds, after which it was removed, drained, and submerged in a tub of sterilized tap water for 30 seconds. This water was then drained and the box was again submerged in a new tub of sterilized water for an additional 90 seconds. After draining, the pieces were removed and dried by crushing between sheets of clean tissue (Kimwipes®) before being placed on plates of acidified potato dextrose agar (APDA). The APDA was produced by autoclaving 16 grams of potato dextrose agar (Difco®) in 500 mL of tap water for 25 minutes and then six drops of 50% lactic acid were added to reduce the growth of bacteria.

Based on the maturity of the sampled plants, there were two, three, or four plates for each plant. The different types of tissue were placed on separate plates of agar. The plates that contained the peanut tissue were incubated at 25° C for 3 to 4 days, after which the fungi that grew on the agar were identified at least as to genus based upon reproductive morphology and characteristics of the colonies. The incidence and the number of colonies per plate were recorded for each fungus. The plates were incubated until all the fungi on the plate were identified or until isolations could be made from specific unknown colonies. Fungal isolations were stored on APDA in glass tubes.

Screening of Selected Isolates for Pathogenicity

In a general study, isolates of 29 fungal genera that were commonly isolated from peanut were used to inoculate peanut plants growing in the greenhouse. The fungal isolates were grown on APDA and inoculum plugs with

a diameter of 4 mm were cut from actively growing mycelium. Peanuts, cv. Florunner, were planted in the greenhouse in small pots containing MetroMix® potting medium. Five weeks after planting, the plants were inoculated with fresh mycelial plugs. Inoculations were made by inserting mycelial plugs into superficial wounds made on the stem between the first and second node, or on the hypocotyls, approximately 1.25 cm below the soil surface. As a control, plugs of APDA without fungi were inserted into similar wounds made on other peanut plants. A list of fungi and number of isolates tested is presented in Table 3-7. Treatments included both the specific fungal isolate used for the inoculation and the site of the inoculation on the plant. The combination of each isolate and each inoculation site was replicated four times. Immediately after inoculation, the plants were either placed in a mist chamber or sealed in colorless, clear plastic bags and stored at 100% relative humidity in a temperature controlled greenhouse for 5 days. The average temperature was 29.4° C, though it often was warmer during the hottest parts of the day. The plants were arranged in a random order. On the fifth day, the plants were removed from the mist chamber or from the plastic bags, and evaluated for signs of fungal growth and symptoms of disease. Evaluations were made every 2 days for the next 9 days.

A second experiment was conducted for fungi that appeared to show some pathogenicity in the general study. Fungal isolates were prepared as before. Florunner was inoculated 14, 28, 45, 51, and 57 days after planting to observe differences in susceptibility based on the age of the host at the time of inoculation. Planting dates were staggered so that all of the inoculations could

Table 3-7. Fungal isolates used in inoculation studies.

Isolate	Fungus	County	General study	Age study	Temperature study	Interaction study
BK-1	*Rhizoctonia solani*	Lake	X			
BK-4	*Cylindrocladium parasiticum*	Santa Rosa	X			
BK-5	*Aspergillus niger*	Santa Rosa	X			
BK-6	*Fusarium* sp.	Alachua	X			
BK-7	*Rhizoctonia solani*	Alachua	X			
BK-8	*Sclerotium rolfsii*	Alachua	X			
BK-9	*Trichoderma* sp.	Alachua	X			
BK-10	*Macrophomina phaseolina*	Alachua	X			
BK-12	*Neocosmospora vasinfecta*	Levy	X			
BK-15	*Curvularia* sp.	Alachua	X			
BK-16	*Curvularia* sp.	Alachua	X			
BK-17	*Macrophomina phaseolina*	Alachua	X			
BK-19	*Curvularia* sp.	Alachua	X			
BK-20	*Bipolaris* sp.	Alachua	X			
BK-21	*Colletotrichum* sp.	Alachua	X			
BK-22	*Helminthosporium*-like	Alachua	X			
BK-23	*Phoma* sp.	Alachua	X			
BK-24	*Calcarisporium* sp.	Alachua	X			
BK-25	*Corynespora* sp.	Alachua	X			
BK-26	*Torula* sp.	Alachua	X			
BK-27	*Robillardia* sp.	Alachua	X			
BK-28	*Pyrenochaeta* sp.	Alachua	X			
BK-29	*Lasiodiplodia theobromae*	Alachua	X			
BK-30	*Laetisaria*-like	Suwannee	X			
BK-31	*Chaetomium* sp.	Levy	X			
BK-32	*Nectria* sp.	Levy	X			
BK-34	*Lasiodiplodia theobromae*	Suwannee	X			
BK-39	*Phomopsis* sp.	Jackson	X			
BK-40	Sterile White Basidiomycete	Suwannee	X			
BK-41	*S. rolfsii*	Suwannee	X			
BK-43	*Eupenicillium* sp.	Levy	X			X

Table 3-7 continued.

Isolate	Fungus	County	General study	Age study	Temperature study	Interaction study
BK-45	*Fusarium* sp.	Alachua	X			
BK-48	*Phoma* sp.	Alachua	X			
BK-49	*Alternaria* sp.	Alachua	X			
BK-51	*R. solani*	Alachua	X			
BK-52	*Fusarium* sp.	Alachua	X			
BK-53	*A. niger*	Alachua	X			
BK-54	*Pithomyces* sp.	Alachua	X			
BK-55	*Leptosphaerulina* sp.	Alachua	X			
BK-56	*Corynespora* sp.	Alachua	X			
BK-59	Sterile White Basidiomycete	Levy	X			
BK-61	*Nigrospora* sp.	Levy	X			
PR-1B	*Fusarium* sp.	Levy		X	X	X
PR-1D	*Fusarium* sp.	Santa Rosa				X
PR-2C	*Penicillium* sp.	Alachua				X
PR-3A	*A. niger*	Santa Rosa				X
PR-3B	*A. niger*	Santa Rosa		X		
PR-5C	Sterile White Basidiomycete	Levy		X		
PR-6A	*R. solani*	Levy		X		
PR-6B	*R. solani*	Santa Rosa				X
PR-6H	*R. solani*	Gadsden				X
PR-8A	*Trichoderma* sp.	Jackson				X
PR-8C	*Trichoderma* sp.	Santa Rosa				X
PR-9B	*Zygorhynchus* sp.	Santa Rosa				X
PR-9C	*Zygorhynchus* sp.	Alachua				X
PR-11C	*M. phaseolina*	Alachua				X
PR-11D	*M. phaseolina*	Suwannee		X	X	
PR-11E	*M. phaseolina*	Santa Rosa				X
PR-13C	*N. vasinfecta*	Suwannee		X	X	
PR-13D	*N. vasinfecta*	Santa Rosa				X
PR-13E	*N. vasinfecta*	Suwannee				X
PR-14A	*L. theobromae*	Santa Rosa				X
PR-14C	*L. theobromae*	Jackson		X	X	
PR-14D	*L. theobromae*	Santa Rosa				X

Table 3-7 continued.

Isolate	Fungus	County	General study	Age study	Temperature study	Interaction study
PR-15D	*C. parasiticum*	Jackson or Santa Rosa		X	X	X
PR-15E	*C. parasiticum*	Santa Rosa				X
QP3	*C. parasiticum*	Gadsden				X
PR-16B	*Cylindrocladiella* sp.	Santa Rosa		X		X
PR-17A	*S. rolfsii*	Suwannee		X	X	X
PR-17D	*S. rolfsii*	Santa Rosa				X
PR-19A	*Chaetomium* sp.	Santa Rosa				X
PR-22B	*Eupenicillium* sp.	Suwannee				X
PR-24A	*Thielavia terricola*	Jackson				X
PR-24B	*Thielavia terricola*	Jackson				X
PR-29B	*Epicoccum* sp.					X
PR-33C	*Phomopsis* sp.	Suwannee		X		
PR-33E	*Phomopsis* sp.	Santa Rosa				X
PR-33F	*Phomopsis* sp.	Santa Rosa				X

be made on the same day. All plants were inoculated after wounding in the hypocotyl approximately 2.54 cm below the soil surface. Each isolate was inoculated into four plants of each age. Isolates that were screened in this study included *Fusarium* sp., *A. niger*, a sterile white basidiomycete, *R. solani*, *M. phaseolina*, *N. vasinfecta*, *L. theobromae*, *C. parasiticum*, *Cylindrocladiella* sp., *S. rolfsii*, and *Phomopsis* spp. (Table 3-7). Experimental procedures and evaluations were as described above.

A final experiment was conducted with selected isolates that were found to be pathogenic to peanut to test if temperature had an effect on disease development. Isolates were prepared as described in the two experiments above. Each isolate was inoculated into the wounded hypocotyls of two plants 2 weeks after planting. The plants were sealed in plastic bags to which misted water had been added to maintain 100% relative humidity. The sealed plants were placed in growth chambers set for temperatures that were considered low, moderate, and high for the soil during the peanut season. These temperatures were 21°C, 27°C, and 32°C. The growth chambers were set for 12 hours of dark and 12 hours of light. Five days after inoculation, evaluations were made on the progress of symptom development and fungal growth on the plants. The plants remained in the growth chamber for an additional 2 weeks. Fungal isolates used in these three studies are listed in Table 3-7.

Screening for *In Vitro* Competitive Interactions Between Selected Fungal Isolates

A number of commonly isolated fungi that were found to be non-pathogenic to peanut were grown on agar plates with known pathogens to test

for the presence of competitive interactions. The non-pathogenic fungi used in this study were selected based on two criteria. The first was their availability in a collection of isolates obtained from peanut plants. The second was characteristics of their growth habit that included colony morphology and the production of pigments that diffused into the growth medium. Isolates such as *Trichoderma* sp. and *Zygorhynchus* sp. had colonies that spread rapidly across an agar plate. Isolates such as *Epicoccum* sp. and *Chaetomium* sp. produced a visible pigment that diffused through the agar medium. Plugs of actively growing mycelium (4mm diameter) from both the pathogen and the non-pathogen were placed in opposition on APDA plates and then incubated at 25° C in a growth chamber set for 12 hours of darkness and 12 hours of light. Each combination of fungi was replicated twice. Observations were then made on a daily basis to determine the result of the fungal growth. Interactions between the competing fungi were described using the following terms. A "barrier" was observed when the two isolates grew together and the further growth of both appeared to stop. "Inhibition" was observed when the growth of one isolate was stopped as it approached, but had not yet made contact with the other isolate. "Overgrowth" occurred when one isolate continued to grow over the second isolate once contact was made and the growth of the second isolate was stopped. "Avoidance" describes the growth of one isolate away from, but not towards the second isolate and is probably related to inhibition. Examples of these interactions are presented in Figure 3-3. Plates were discarded when mycelial expansion was complete.

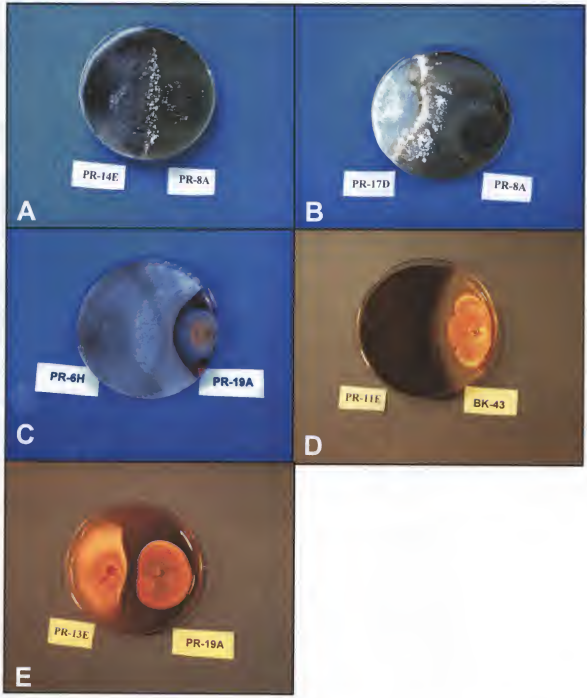


Figure 3-3. Interactions between fungi on acidified potato dextrose agar. A. "Barrier" interaction between *Lasiodiplodia theobromae* (PR-14E) and *Trichoderma* sp. (PR-8A). B. "Overgrowth" of *Sclerotium rolfsii* (PR-17D) by *Trichoderma* sp. C. "Inhibition" *of Rhizoctonia solani* (PR-6H) by *Chaetomium* sp. (PR-19A). D. Inhibition of *Macrophomina phaseolina* (PR-11E by *Eupenicillium* sp. (BK-43). E. "Avoidance" of *Neocosmospora vasinfecta* (PR-13E) from *Chaetomium* sp. (PR-19A).

Results

Field Data

There was great variation between commercial fields in both 1995 and 1996. The soil types varied from sands in the southern sampling areas to sandy loams and sandy clay loams in the Panhandle. In 1995, planting dates varied from 27 March to 25 May. In 1996, planting dates varied from April 5 to May 10. In both years, most commercial fields were planted with runner-type varieties, with only a single field planted to Virginia-type in 1995 and 1996, and a single field of Valencia-type in 1995. In 1995, Florunner and GK-7 were the most popular cultivars, while in 1996 GK-7 was the most popular variety. Over both seasons, 8% of fields were planted to peanut following peanut, 24% of fields were planted to peanut after a year away from peanut, 52% of fields were on a 3-year rotation with peanut, and 16% of fields were on a 4-year or better rotation (Tables 3-1 and 3-2).

The growers reported their fungicide programs and harvest information from most of the commercial fields that were assessed during this survey (Table 3-3). Harvests occurred between August and October in 1995 and 1996. Chlorothalonil was used in 85.7% of these fields; tebuconazole was used in 90.4% of fields, benomyl was used in 38% of fields, mancozeb was used in 9.5% of fields, while flutolanil was only used in a single field. Additional gypsum was applied on all but two of the commercial fields. In 1995, harvested yields varied from 2.2 to 6.9 metric tons per hectare. In 1996 yields varied from 3.1 to 6.2 metric tons per hectare. In 1995 and 1996, the largest yields were recorded in

fields 101 (6132 kg ha^{-1}), 103 (4942 kg ha^{-1}), and 201 (5554 kg ha^{-1}), where bahiagrass had been planted for at least four years since the previous crop of peanuts (Table 3-1 and 3-2). The yield in field 105 was not as high as in these other fields (3497 kg ha^{-1}), although bahiagrass had been present in that field continuously for 15 years. The poorest yields in 1995 were from fields 102 (not harvested because of losses to soilborne disease) and 108 (1950 kg ha^{-1}). Peanut had been planted in each of these fields in either 1993 or 1994. Field 202 had one of the lowest yields in 1996 (2800 kg ha^{-1}) and peanut had been planted in that field in 1995.

Isolated fungi

In 1995, fungi were isolated from 1587 peanut plants, and in 1996 isolations were made from 1270 plants. The number of plants sampled at each field site is presented in Table 3-4. In this survey, fungi from 48 different genera were identified. At least two fungal types were not identified. The phyla Ascomycota, Basidiomycota, Zygomycota, Oomycota, and the form-phylum Deuteromycota were represented. The largest percentage of genera belonged to the Deuteromycota (Figure 3-4). As the deuteromycetes were likely to be the anamorphic stages of fungi in the Ascomycota, nearly 75% of all of the fungi isolated from the below ground parts of the peanut plant belonged to this group. The phylum Oomycota was represented by a single genus, *Pythium*, and two species, *Pythium myriotylum* and *Pythium irregulare*. *Pythium myriotylum* was much more common than *Pythium irregulare*.

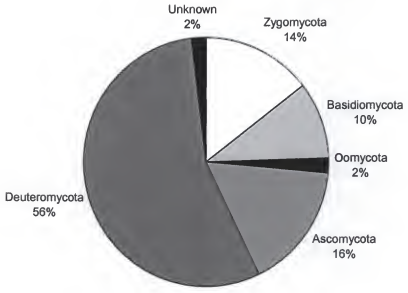


Figure 3-4. Distribution of fungal genera by phylum and form-phylum (Deuteromycota) that were isolated during 1995 and 1996 from the roots, hypocotyls, pods, and pegs of peanut grown in Florida.

Fusarium spp., *Penicillium* spp., *Trichoderma* spp., and *Aspergillus niger* were the fungi that were most commonly isolated from seedlings and young peanut plants (Table 3-8). These fungi were isolated from at least 70% of the commercial fields and from at least 30% of the plants during the initial sampling trips. Fungi that were also isolated from these young plants, but not with the abundance of those above, included *Macrophomina phaseolina*, *Rhizopus* spp., *Rhizoctonia solani*, *Thielavia* terricola, *Neocosmospora vasinfecta*, *Chaetomium* sp., and *Aspergillus flavus*. Important pathogens, such as *Cylindrocladium parasiticum*, *Sclerotium rolfsii*, *Lasiodiplodia theobromae*, and *Pythium* spp., were isolated infrequently during the early growth of the peanut plants

A compilation of the fungi isolated from the peanut plants over the entire season with the incidence of the fungi both in terms of number of fields and the average maximum incidence is presented in Table 3-9. The "average maximum incidence" was calculated by averaging the highest incidences obtained for a specific fungus from each commercial field during a season. The sampling trip on which the highest incidence was recorded often varied between fields. Fields from which the fungus was not recovered at least once were not included in this calculation. Some fungi, such as *Fusarium* spp., *Penicillium* spp., *A. niger*, and *Trichoderma* spp., were isolated in every commercial field in which plants were sampled in 1995 and 1996. These same fungi infected nearly all of the plants that were sampled at some point in the season. Other fungi, such as *R. solani, M. phaseolina, Chaetomium* sp., *Curvularia* spp., *Alternaria* sp., *L. theobromae, Phoma* sp., and *Nigrospora* sp., were found in nearly every commercial field that

Table 3-8. Incidence of fungi during peanut seedling and vegetative stages.

Fungus	Field incidence (%)[y]		Average incidence (%)[z]	
	1995	1996	1995	1996
Fusarium spp.	100	100	74.9	78
Penicillium spp.	100	100	55.9	72
Trichoderma spp.	92.8	77.8	38.9	32.1
Aspergillus niger	71.4	88.9	41.5	49.4
Macrophomina phaseolina	71.4	66.7	16.7	40
Rhizopus spp.	64.3	77.8	38.3	56.3
Rhizoctonia solani	50	100	31.4	10.5
Thielavia terricola	42.8	11.1	36.2	5
Neocosmospora vasinfecta	35.7	88.9	18.2	25
Chaetomium sp.	35.7	55.5	17	13
Aspergillus flavus	35.7	77.8	11.0	28.6
Torula sp.	21.4	11.1	21.7	35
Zygorhynchus sp.	21.4	11.1	11.7	10
Nectria sp.	21.4	0	11.7	0
Colletotrichum sp.	21.4	11.1	10	15
Nigrospora sp.	21.4	11.1	6.7	15
Mucor sp.	21.4	0	6.7	0
Curvularia sp.	21.4	22.2	5	5
Alternaria sp.	14.3	11.1	7.5	5
Cylindrocladium parasiticum	14.3	11.1	5	15
Phoma sp.	7.1	6.7	10	5.8
Sclerotium rolfsii	7.1	11.1	5	5
Phomopsis sp.	7.1	11.1	5	5
Eupenicillium sp.	7.1	33.3	5	11.7
Epicoccum sp.	7.1	0	5	0
Cylindrocladiella sp.	0	11.1	0	5
Choanephora cucurbitarum	0	11.1	0	5

Table 3-8 continued.

Fungus	Field incidence (%)[y]		Average incidence (%)[z]	
	1995	1996	1995	1996
Cunninghamella sp.	0	22.2	0	10
Pythium spp.	0	11.1	0	10
Sterile white basidiomycete	0	22.2	0	5
Lasiodiplodia theobromae	0	44.4	0	17.5
Cladosporium sp.	0	11.1	0	5

[y] Field Incidence is the percentage of commercial fields in which a specific fungus was found during the seedling stage.
[z] Average incidence is the mean incidence of the fungus determined from only those fields in which it was recovered during the seedling stage of growth.

Table 3-9. Abundance of soilborne fungi isolated from commercial and research peanut fields in Florida over an entire season.

Phylum	Genus or species	Percentage of fields with fungus		Average maximum incidence[z]	
		1995	1996	1995	1996
Basidiomycota (anamorphs)	*Rhizoctonia solani*	100	100	54	43.2
	Sclerotium rolfsii	44	60	10	9.2
	Laetisaria-like	scarce	none	scarce	scarce
	Macrophomina phaseolina	100	100	73.7	63.2
	Sterile White Basidiomycete	16.7	30	5	3.8
Ascomycota (teleomorphs)	*Nectria* sp.	50	30	12.3	5.6
	Chaetomium sp.	88.8	90	29.7	24.3
	Thielavia terricola	88.8	30	25.8	10.2
	Sordaria sp.	22	20	10	5
	Gelasinospora sp.	0	10	0	scarce
	Leptosphaerulina sp.	22	10	11.7	5.7
	Neocosmospora vasinfecta	100	100	70.6	68.4
Zygomycota	*Rhizopus* spp.	94.4	100	52.9	53.1
	Mucor spp.	100	100	52.0	55.2
	Zygorhynchus sp.	55.5	80	14.7	12.5
	Choanephora cucurbitarum	83.3	80	27.2	32.5
	Choanephora-like	33.3	100	5	27.2
	Cunninghamella spp.	77.7	50	12.2	9.3
	Blakeslea trispora.	0	70	0	scarce
	Poitrasia circinens	unknown	unknown	scarce	scarce
Oomycota	*Pythium* spp.	33	40	35	20

[z]Average maximum incidence was calculated only from those fields in which a fungus was isolated at least once. It refers to the maximum incidence of a fungus observed for a field on a single sampling date.

Table 3-9 continued.

Phylum	Genus or species	Percentage of fields with fungus		Average maximum incidence	
		1995	1996	1995	1996
Deuteromycota	*Alternaria* sp.	100	90	54.7	33.7
	Aspergillus flavus	100	100	26.2	30.7
	Aspergillus niger	100	100	83.1	75.3
	Bipolaris sp.	55.5	10	8.7	4.4
	Calcarisporium-like	6	0	scarce	0
	Cladosporium sp.	72.2	90	15.5	8.4
	Colletotrichum sp.	55.5	70	13.4	10.6
	Corynespora sp.	6	10	scarce	scarce
	Curvularia spp.	100	90	21.1	12.9
	Cylindrocarpon sp.	scarce	scarce	scarce	scarce
	Cylindrocladiella sp.	0	10	0	scarce
	Cylindrocladium parasiticum	39	50	32.6	32.5
	Epicoccum sp.	28	10	11.7	5.9
	Eupenicillium sp.	72.2	60	26.4	24.3
	Fusarium spp.	100	100	100	100
	Gliocladium sp.	33.3	0	5	0
	Gloeosporium sp.	27.7	10	7.0	4.0
	Lasiodiplodia theobromae	77.7	90	26.3	37.0
	Nigrospora sp.	100	90	18.0	22.2
	Paecilomyces sp.	33.3	60	7.8	23.0
	Penicillium spp.	100	100	99.3	88.2
	Pestalotia sp.	72.2	70	13.9	6.3
	Phoma sp.	100	100	38.8	16.5
	Phomopsis sp.	83.3	90	34.8	35.5
	Pithomyces sp.	6	0	5	0
	Pyrenochaeta sp.	6	0	scarce	0
	Robillardia sp.	6	0	5	0
	Torula sp.	22.2	10	21.7	8.9
	Trichoderma spp.	100	100	89.7	77.7

was sampled, but not with the high incidence of fungi such as *Fusarium* spp. Other fungi, such as *S. rolfsii*, *C. parasiticum*, and *Pythium* spp., were isolated in fewer fields and in fewer plants from those fields. Some fungi, such as *Robillardia* sp., *Pyrencochaeta* sp., and *Pithomyces* sp., were isolated rarely during the survey.

The sampling sites surveyed in 1995 and 1996 can be grouped into five regions. These regions include Santa Rosa County, Jackson County, Suwannee County, Levy County, and the Alachua-Columbia Counties. The percentage of fields in each region from which individual genera of fungi were isolated is presented in Table 3-10. The proportion of fields from which many of these fungi were isolated did not vary across Florida. Fungi included in this group were *R. solani*, *N. vasinfecta*, *Rhizopus* spp., *Mucor* spp., *A. niger, A. flavus, Phoma* sp., as well as others. Fungi that were present in a larger proportion of fields in the Panhandle than in peninsular Florida included *C. parasiticum* and *Cylindrocladiella* sp., while fungi such as *Zygorhynchus* sp. and *Torula* sp. were more common in peninsular Florida. *Cylindrocladium parasiticum* was not detected in Alachua or Columbia Counties in either year.

Pathogenicity

Three studies were conducted to evaluate fungal isolates for pathogenicity to peanut. Multiple isolates of 30 fungi belonging to the Ascomycota, Basidiomycota, and Deuteromycota were tested. The only species of importance within this group that was not evaluated was *A. flavus*. This fungus

Table 3-10. Percentage of fields from which fungi were isolated based upon five regions in Florida.

	Santa Rosa		Jackson		Suwannee		Columbia Alachua		Levy	
Fungus	1995 3[z]	1996 3	1995 4	1996 2	1995 6	1996 3	1995 2	1996 1	1995 3	1996 1
Alternaria sp.	100	100	100	100	100	66.7	100	100	100	100
Aspergillus flavus	100	100	100	100	100	100	100	100	100	100
Aspergillus niger	100	100	100	100	100	100	100	100	100	100
Bipolaris sp.	0	0	50	50	100	0	100	0	0	0
Blakeslea trispora	0	33.3	0	50	0	100	0	100	0	100
Brown-unknown	33.3	100	100	100	66.7	100	100	100	66.7	0
Chaetomium sp.	100	100	100	100	83.3	100	100	100	66.7	0
Choanephora cucurbitarum	100	66.7	100	100	83.3	100	100	100	33.3	0
Cladosporium sp.	33.3	100	100	50	66.7	100	100	100	66.7	100
Colletotrichum sp.	100	100	75	50	50	33.3	100	100	0	100
Corynespora sp.	0	0	0	0	0	0	50	100	0	0
Cunninghamella sp.	100	66.7	100	100	83.3	0	50	100	33.3	0
Curvularia spp.	100	66.7	100	100	100	100	100	100	100	100
Cylindrocladiella sp.	0	33.3	0	0	0	0	0	0	0	0
Cylindrocladium parasiticum	66.7	100	25	100	50	0	0	0	33.3	0
Epicoccum sp.	33.3	0	25	50	33.3	0	50	100	0	0
Eupenicillium sp.	0	33.3	100	100	66.7	66.7	100	100	100	0
Fusarium spp.	100	100	100	100	100	100	100	100	100	100
Gelasinospora sp.	0	0	0	50	0	0	0	0	0	0
Gliocladium sp.	66.7	0	25	0	50	0	0	0	0	0
Gloeosporium sp.	66.7	0	0	0	33	33.3	0	0	33.3	0
Lasiodiplodia theobromae	100	100	100	100	83.3	100	50	100	33.3	0
Leptosphaerulina sp.	33.3	33.3	25	0	0	0	50	0	33.3	0
Macrophomina phaseolina	100	100	100	100	100	100	100	100	100	100
Mucor spp.	100	100	100	100	100	100	100	100	100	100
Nectria sp.	0	33.3	75	0	33.3	33.3	50	100	100	0
Neocosmospora vasinfecta	100	100	100	100	100	100	100	100	100	100

Table 3-10 continued.

	Santa Rosa		Jackson		Suwannee		Columbia Alachua		Levy	
Fungus	1995 3	1996 3	1995 4	1996 2	1995 6	1996 3	1995 2	1996 1	1995 3	1996 1
Nigrospora sp.	100	100	100	100	100	66.7	100	100	100	100
Paecilomyces sp.	0	66.7	0	0	50	66.7	100	100	33.3	100
Penicillium spp.	100	100	100	100	100	100	100	100	100	100
Pestalotia sp.	100	66.7	50	50	66.7	66.7	0	100	66.7	100
Phoma sp.	100	100	100	100	100	100	100	100	100	100
Phomopsis sp.	100	66.7	100	100	66.7	100	50	100	66.7	100
Pythium spp.	66.7	33.3	25	0	33.3	66.7	50	100	0	0
Rhizoctonia solani	100	100	100	100	100	100	100	100	100	100
Rhizopus spp.	100	100	100	100	83.3	100	100	100	100	100
Sclerotium rolfsii	33.3	33.3	75	100	33.3	66.7	100	100	0	0
Sordaria sp.	0	0	25	50	17	33.3	0	0	33.3	0
Sterile White Basidiomycete	0	0	0	0	33.3	33.3	0	100	33.3	100
Thielavia terricola	100	100	75	0	83.3	0	100	100	100	0
Torula sp.	0	0	0	0	33.3	33.3	50	0	33.3	0
Trichoderma spp.	100	100	100	100	100	100	100	100	100	100
Zygorhynchus sp.	33.3	66.7	50	50	50	100	50	100	100	100

[z] The figure beneath each year is the number of fields that were sampled in that region.

was omitted because of possible human health risks involved with its potential for production of aflatoxin. Fungi from the Zygomycota and the Oomycota were not evaluated in these studies, as isolates of *Pythium* spp., *Rhizopus* spp., *Mucor* spp., *Cunninghamella* sp., *Blakeslea trispora*, *Choanephora cucurbitarum*, and *Poitrasia circinens* were not collected.

In the largest of the three pathogenicity studies, 30 different genera of fungi were inoculated into peanut plants both in the hypocotyl and in the lower stem (Table 3-11). When more than one isolate of a fungus was available, the inoculations were repeated with multiple isolates, but usually not for the same isolates. The isolates were either rated as "non-pathogens," "unlikely pathogens," "weak pathogens," "moderate pathogens," or "strong pathogens" to peanut plants at this age. "Non-pathogens" produced symptoms similar to the control, which might include a discoloration of the wound site and vascular tissue. Examples of non-pathogens included *Colletotrichum* sp., *Cylindrocladiella* sp., *Trichoderma* sp., and *Laetisaria* sp. "Unlikely pathogens" produced small, localized lesions at the site of inoculation. Examples of unlikely pathogens were *Alternaria* sp., *Bipolaris* sp., *Curvularia* sp., *Leptosphaerulina* sp., and *Torula* sp. "Weak pathogens" were those genera for which at least one isolate produced expanding lesions at least some of the time. These expanding lesions did not affect the health of the plant. Examples of weak pathogens were *C. parasiticum* and *Phomopsis* sp. "Moderate pathogens" were defined as those pathogens that could, on occasion, produce wilt symptoms in these plants,

Table 3-11. Relative pathogenicity of fungal isolates inoculated into five-week-old peanut plants.

Fungus	Rating[y]					
	Isolates	Non pathogen	Unlikely pathogen	Weak pathogen	Moderate pathogen	Strong pathogen
Alternaria sp.	1		X			
Aspergillus niger	2				X	
Bipolaris sp.	1		X			
Calcarisporium sp.	1		X			
Chaetomium sp.	2		X			
Colletotrichum sp.	1	X				
Corynespora sp.	2	X				
Curvularia spp.	3		X			
Cylindrocladiella sp.	1	X				
Cylindrocladium parasiticum	1			X		
Eupenicillium sp.	1	X				
Fusarium sp.[z]	4		X			
Helminthosporium-like	1		X			
Laetisaria sp.	2	X				
Lasiodiplodia theobromae	2					X
Leptosphaerulina sp.	2		X			
Macrophomina phaseolina	2	X				
Nectria sp.	1	X				
Neocosmospora vasinfecta	2		X			
Nigrospora sp.	1		X			
Phoma sp.[z]	2		X			
Phomopsis sp.[z]	2			X		
Pithomyces sp.	1	X				
Pyrenochaeta sp.	1		X			
Rhizoctonia solani[z]	3				X	
Robillardia sp.	1	X				
Sclerotium rolfsii	1					X
Sterile white basidiomycete	2	X				
Torula sp.	1		X			
Trichoderma sp.	1	X				

[y] Ratings for pathogenicity are for this test of mature plants only. Some fungi were pathogenic on plants of different ages.
[z] Variability existed in virulence of isolates.

though the wilt was limited. Examples of moderate pathogens were *A. niger* and *R. solani.* Finally, "strong pathogens" were defined as those fungi that are able to kill at least some of the plants into which they were inoculated. Examples of strong pathogens were *L. theobromae* and *S. rolfsii.*

In the second evaluation for pathogenicity, fungal isolates of special interest were inoculated into wounded plants that ranged in age from 14 to 57 days after planting at the time of inoculation. Four plants at each age were inoculated with an isolate; this study was conducted only once. The fungal isolates were selected for further scrutiny based upon the results from the first screen or suggestion in the literature that they might be pathogenic in some instances. The results of this study are presented in Table 3-12. A sterile white basidiomycete, *R. solani*, *M. phaseolina*, *Cylindrocladiella* sp., and *Phomopsis* sp. did not cause disease in any of the plants evaluated in this study. *Lasiodiplodia theobromae*, *S. rolfsii*, *C. parasiticum*, *A. niger*, *N. vasinfecta,* and *Fusarium* spp. were found to kill peanut plants on at least one occasion. *Lasiodiplodia theobromae* and *C. parasiticum* caused severe disease and death on plants of all ages, while disease caused by *S. rolfsii* was most severe on plants that were inoculated during late vegetative and early reproductive growth stages. *Neocosmospora vasinfecta* only caused disease in plants that were inoculated during vegetative growth.

Five fungi of potential importance were further screened for pathogenicity to peanut at three different ambient temperatures (Table 3-13). This experiment was not repeated. Plants inoculated with *M. phaseolina* remained healthy at all

Table 3-12. Pathogenicity of selected fungal isolates inoculated into Florunner peanut at five different ages and growth stages. Plants were inoculated 11/21/96; final evaluation made 12/17/96.

Fungus	Planting date	Growth stage at inoculation[z]	Growth stage at final rating[z]	% Wilted/ necrotic plants 12/17/96	% Dead plants 12/17/96
Control	9/25/96	R3*	R5	0	0
	10/1/96	R2	R3-R5	0	0
	10/7/96	R1	R2-R4	0	0
	10/24/96	V5-V6	4xR1	0	0
	11/7/96	V3	3xR1 1xV	0	0
Fusarium sp.	9/25/96	R3	R5-R6	0	0
	10/1/96	R2	R2	25	25
	10/7/96	R1	R2-R4	0	0
	10/24/96	V5-V6	4xR1	0	0
	11/7/96	V3	1xR1 3xV	50	0
Aspergillus niger	9/25/96	R3	R5-R6	50	50
	10/1/96	R2	R2	75	25
	10/7/96	R1	R1	50	50
	10/24/96	V5-V6	2xR1 1xV	0	25
	11/7/96	V3	N/A	0	100
Sterile White Basidiomycete	9/25/96	R3	R5	0	0
	10/1/96	R2	R2-R5	25	0
	10/7/96	R1	R2-R3	0	0
	10/24/96	V5-V6	1xR2,3xR1	0	0
	11/7/96	V3	4 V	0	0
Rhizoctonia solani	9/25/96	R3	R5-R6	0	0
	10/1/96	R2	R2-R3	0	0
	10/7/96	R1	R2-R3	0	0
	10/24/96	V5-V6	4xR1	0	0
	11/7/96	V3	4xV	0	0
Macrophomina phaseolina	9/25/96	R3	R5	0	0
	10/1/96	R2	R3-R5	0	0
	10/7/96	R1	R1-R4	0	0
	10/24/96	V5-V6	4xR1	0	0
	11/7/96	V3	1xR1 3xV	0	0

Table 3-12 continued.

Fungus	Planting date	Growth stage at inoculation	Growth stage at final rating	% Wilted / necrotic plants 12/17/96	% Dead plants 12/17/96
Neocosmospora vasinfecta	9/25/96	R3	R5-R6	0	0
	10/1/96	R2	R2-R3	0	0
	10/7/96	R1	R1-R3	0	0
	10/24/96	V5-V6	1xR1 1xV	0	50
	11/7/96	V3	4xV	50	25
Lasiodiplodia theobromae	9/25/96	R3	R3	25	75
	10/1/96	R2	N/A	0	100
	10/7/96	R1	N/A	0	100
	10/24/96	V5-V6	N/A	0	100
	11/7/96	V3	N/A	0	100
Cylindrocladium parasitcum	9/25/96	R3	R5	25	75
	10/1/96	R2	R2-R5	0	50
	10/7/96	R1	R3	25	75
	10/24/96	V5-V6	N/A	0	100
	11/7/96	V3	N/A	0	100
Cylindrocladiella sp.	9/25/96	R3	R5	0	0
	10/1/96	R2	R2	0	0
	10/7/96	R1	R1-R3	0	0
	10/24/96	V5-V6	4xR1	0	0
	11/7/96	V3	1xR1 3xV	0	0
Sclerotium rolfsii	9/25/96	R3	R5	0	25
	10/1/96	R2	R2-R5	25	0
	10/7/96	R1	R2-R3	50	50
	10/24/96	V5-V6	1xR1	25	75
	11/7/96	V3	4xV	100	0
Phomopsis spp.	9/25/96	R3	R5-R6	0	0
	10/1/96	R2	R2-R4	0	0
	10/7/96	R1	R2-R3	0	0
	10/24/96	V5-V6	3xR1 1xV	0	0
	11/7/96	V3	4xV	0	0

[z] A summary of the growth stages of the peanut plant is presented in Table 3-5; briefly, V1-V6 = vegetative stages in increasing maturity and R = reproductive stages with R1 = beginning bloom, R2 = beginning peg, R3 = beginning pod formation, R4 = full pod formation, R5 = beginning seed formation, and R6 = the full seed stage of development.

Table 3-13. Pathogenicity of selected fungi 25 days after inoculation of 14-day-old Florunner peanut seedlings at three different temperatures.

Fungus	Temperature (°C)	Disease Severity			
		Healthy	Necrosis (no wilt)	Partial wilt	Complete wilt and death
Control	21	2[z]			
	27	2			
	32	2			
Fusarium sp.	21	1			1
	27	1			1
	32	2			
Macrophomina phaseolina	21	2			
	27	2			
	32	2			
Neocosmospora vasinfecta	21	2			
	27	2			
	32	1	1		
Lasiodiplodia theobromae	21				2
	27				2
	32	1			1
Cylindrocladium parasiticum	21				2
	27		1		1
	32	2			
Sclerotium rolfsii	21		1	1	
	27			1	1
	32				2

[z] Numbers (1 or 2) represent the number of plants per two inoculated plants that showed the symptoms specific for that column in the table.

temperatures. Symptoms developed in the plants inoculated with *N. vasinfecta* only at 32°C. One of the plants infected with *Fusarium* spp. was killed at 21°C and 27°C, but not at 32°C. Disease symptoms associated with *C. parasiticum* were more severe at the cooler temperatures, while the plants placed in the growth chamber at 32°C remained healthy. Disease symptoms associated with *S. rolfsii* appeared to be most severe at the warmer temperatures. Finally, inoculation with *L. theobromae* was lethal at all temperatures.

Antagonism and Competitive Interactions

The results of the study of competitive interactions between eight pathogenic fungi and ten non-pathogenic fungi are presented in the form of a matrix in Table 3-14 and examples of interactions are presented in Figure 3-3. The non-pathogenic fungi will be referred to as "antagonists" in this discussion. Variations of four basic trends were observed. As described in the Materials and Methods, the basic interactions included a physical barrier, inhibition of growth, an avoidance response, and an overgrowth of one fungus by another.

One of the most common interactions between two fungi was the barrier (Table 3-14). When a barrier was observed, the growth of each fungus appeared to be obstructed simply by the physical presence of the other fungus. Neither fungus appeared to affect the health or otherwise natural growth of the other. Examples of barriers were obtained for pairs of fungi such *as L. theobromae* and *Zygorhynchus* sp., *M. phaseolina* and *Phomopsis* sp., and *A. niger* and *Trichoderma* sp.

Table 3-14. Competitive interactions between pathogenic isolates and selected non-pathogenic antagonists.

Antagonistic fungus and isoalte	*Penicillium* sp. P2C	*Trichoderma* sp. P8A	*Trichoderma* sp. P8C	*Zygorhynchus* sp. P9B	*Zygorhynchus* sp. P9C	*Cylindrocladiella sp.* P16B	*Chaetomium* sp. P19A	*Eupenicillium* sp. P22B	*Eupenicillium* sp BK43	*Thielavia terricola* P24A	*Thielavia terricola* P24B	*Epicoccum* sp. P29B	*Phomopsis* sp. P33E	*Phomopsis* sp. P33F
Pathogen and isolate														
Fusarium sp. P1B	B[q]	B	B	B	B	B	Al[r]	Aav[s]	Aav	B	B	Al	B	B
Fusarium sp. P1D	B	B	B	B	B	NC[t]	NC	Aav	Aav	NC	NC	NC	B	B
Aspergillus niger P3A	B	B	B	PO[u]	PO	PO-w[v]	Pl[w]	Aav	Aav	PO	PO	NC	--	--
Aspergillus niger P3B	B	B	B	B	PO	PO-w	Al-w	Aav	Aav	NC	---	NC	B+l[x]	I
Rhizoctonia solani P6B	B	AO[y]	AO	B	B	B	Al	B	B	B	B	Al-w	B	PO
Rhizoctonia solani P6H	PO-w	AO	AO	B	B	PO	Al	w	PO-w	B	B	B	B	B
Macrophomina phaseolina P11C	Al-w	AO	AO	Al-w	AO-w	Al-w	Al	Al	Al	Al-w	Al-w	Al	B	B
Macrophomina phaseolina P11E	Al-w	AO	AO	B	B	B	Al	Al	Al	Al-w	Al-w	Al	B	B
Neocosmospora vasinfecta P13D	Aav	AO	B	B	B	NC	Pav[z]	Aav	Aav	B	B	Al-w	B	B
Neocosmospora vasinfecta P13E	Aav	AO	B	B	B	NC	Pav	Aav	Aav	B	B	Al-w	B	B

Table 3-14 continued.

Antagonistic fungus and isolate	*Penicillium* sp. P2C	*Trichoderma* sp. P8A	*Trichoderma* sp P8C	*Zygorhynchus* sp. P9B	*Zygorhynchus* sp. P9C	*Cylindrocladiella sp.* P16B	*Chaetomium* sp. P19A	*Eupenicillium* sp. P22B	*Eupenicillium* sp. BK43	*Thielavia terricola* P24A	*Thielavia terricola* P24B	*Epicoccum* sp. P29B	*Phomopsis* sp. P33E	*Phomopsis* sp. P33F
Pathogen and isolate														
Lasiodiplodia theobromae P14A	B	B	B	B	B	B	PO	B	B	PO	PO	PO	B	B
Lasiodiplodia theobromae P14D	B	B	AO-w	B	B	B	PO	B	B	B	B	PO-w	B	B
Cylindrocladium parasiticum P15D	B	B	B	B	B	B	PO	Aav	Aav	PO	PO	PO	B	B
Cylindrocladium parasiticum P15E	PO	B	B	PO	PO	B	PO	PO	PO	PO	PO	PO	B	B
Cylindrocladium parasiticum QP3	NC	AO	PI	B	B	B	I	Aav	Aav	Aav	Aav	Aav	PI	PI
Sclerotium rolfsii . P17A	PO	--	--	PO	PO	PO	B+AI	PO	PO	PO	PO	PO	PO	PO
Sclerotium rolfsii . P17D	PO	AO-w	AO-w	PO	PO	PO	PO-w	PO	PO	PO	PO	B	PO	PO

[q] B = physical barrier to growth of either fungus.
[r] AI = growth of pathogen is inhibited by antagonist.
[s] Aav = antagonist grows away from and avoids the pathogen.
[t] NC = contact is not made between isolates due to slow growth.
[u] PO = pathogen overgrows antagonist. [v] –w = interaction occurs, but is weak or limited.
[w] PI = growth of antagonist is inhibited by pathogen.
[x] I = indeterminate inhibition between isolates.
[y] AO = antagonist overgrows pathogen. [z] Pav = pathogen grows away from antagonist.

Overgrowth of one fungus by the other could either be by the antagonist, as in the case of *Trichoderma* sp. and *R. solani*, or by the pathogen, as in the case of *S. rolfsii* and *Zygorhynchus* sp. (Table 3-14). Overgrowth of one fungus by another was not always complete, as in the case of *Trichoderma* sp. and *S. rolfsii*. However, in those cases, one fungus was clearly able to reduce or inhibit the growth of the other fungus. Although it was not possible to determine if the dominant fungus was actually parasitizing the weaker fungus, in all cases it appeared that the dominant fungus had out-competed the other for space and resources on the agar.

Some fungi were able to form a zone of inhibition between themselves and the other fungus on the plate of agar (Table 3-14). As in the case of fungi such as *Chaetomium* sp., *Epicoccum* sp., and one isolate of *C. parasiticum* (QP3), the zone of inhibition was clearly associated with the diffusion of a pigment from the fungus through the agar. The growth of some opposing fungi was affected by the progress of this pigment and their growth was severely limited in the zone. In other cases, the growth of one fungus was clearly inhibited around the colony of the opposing fungus, though the agar within the zone of inhibition did not appear colored or different from the rest of the agar on the plate. The growth of *M. phaseolina* with respect to both a *Eupenicillium*-like fungus and *T. terricola* demonstrated this type of inhibition.

The avoidance interaction may be related in some way to the inhibition mentioned above, but can be even more dramatic. In avoidance, the growth of one fungus appears natural in the direction away from the opposing fungus, but

severely restricted towards the opposing fungus. An example of avoidance occurred between *N. vasinfecta* and *Chaetomium* sp.

Finally, it should be noted that the interactions between opposing fungal isolates on the agar plates were often subtle or weak and might appear as a combination of more than one of the categories described above. These interactions made evaluations and descriptions more difficult and are annotated as such in Table 3-14.

Discussion

In a survey of peanut plants sampled from multiple sites around the state of Florida, 48 different genera of fungi were identified. Many of these fungi were abundant. They were found in the majority of sites that were sampled and their average maximum incidence was 75% or greater. Examples of such fungi include *Macrophomina phaseolina*, *Neocosmospora vasinfecta*, *Fusarium* spp., *Penicillium* spp., *Trichoderma* spp., and *Aspergillus niger*. Other fungi were common, in the sense that they were isolated from many fields, but not in the abundance of those mentioned above. Examples of such fungi included *R. solani*, *Chaetomium* sp., *Rhizopus* spp., *Mucor* spp., *A. flavus*, *Curvularia* spp., *Alternaria* sp., and *L. theobromae*. None of the fungi that were found in only a few fields had a high maximum incidence in those fields. The next group of fungi included those that were found in fewer fields and with a lower average maximum incidence. Examples from this group included *Pythium* spp., *Nectria* sp., *Torula* sp., *Eupenicillium* sp., *S. rolfsii*, and *C. parasiticum*. Interestingly, three important pathogens fell into this category. Another group included those

fungi that were found in only a few fields and never with high frequency. Examples from this group included a sterile white basidiomycete, *Sordaria* sp., *Leptosphaerulina* sp., *Epicoccum* sp., and *Gliocladium* sp. The final group of fungi included those that were rarely isolated. Examples included *Laetisaria* sp., *Gelasinospora* sp., *Robillardia* sp., *Pyrenochaeta* sp., *Cylindrocladiella* sp., *Calcarisporium* sp., and *Pithomyces* sp.

The diversity of soilborne fungi isolated from peanut in Florida is similar to the diversity of soilborne fungi isolated from peanut pods collected in Georgia, Alabama, North Carolina, South Carolina, Oklahoma, Texas, and Virginia (12, 13, 14, 86, 95, 97, 99). The studies by Hollowell, Shew, and Beute (95) in North Carolina, and Hotchkiss and Baxter (97) in South Carolina were limited to the fungi associated with pod and peg rotting. With the exception of isolations of *Sclerotinia minor* in North Carolina, the fungi identified by those researchers were also isolated in Florida.

Hanlin (86) evaluated over 4000 isolates of fungi from peanut pods and seeds collected in six states over a period of 4 years. He was able to identify 70 genera and 146 species of soilborne fungi during this study. Hanlin (86) did not note the percentage of samples from which a particular fungus was isolated, but he noted the states in which the fungus was recovered. The fungi commonly isolated in Florida were also found in many of the six states assessed by Hanlin (86). Those fungi identified in Hanlin's study (86), but not found in Florida, were normally isolated in only one or two of the six states. Fungi identified in Florida, but not mentioned in Hanlin's study included species of *Blakeslea, Poitrasia,*

Gelasinospora, Gloeosporium, Corynespora, Torula, and *Cylindrocladiella*. These fungi were not commonly isolated in Florida.

Baird et al. (12, 13, 14) evaluated the soilborne fungi associated with peanut pods produced near Tifton, Georgia, during 1990-1993. They isolated 44 genera of fungi. The fungal genera that were identified in those studies, but not identified in Florida had very low incidences of recovery. Most of the genera isolated in Florida, but not in those studies from Georgia, were found with low incidences. However, some genera, including *Choanephora, Zygorhynchus*, and *Phomopsis*, were recovered in Florida with some abundance but were not identified in those studies from Georgia. This may be the result of isolations from pods alone in Georgia.

Jackson (99) found 28 genera of soilborne fungi associated with peanut pods from Georgia during 1965 and 1966. The genera *Starkeyomyces* and *Melanconium* were isolated infrequently by Jackson (99) and were not found in Florida during 1995 and 1996.

The isolation frequencies for specific fungi in this study compared favorably between 1995 and1996 both in terms of the number of fields and the average maximum incidence (Table 3-9). Examples include the isolation frequencies of *R. solani*, *S. rolfsii, M. phaseolina*, *Chaetomium* sp., *Pythium* spp., *A. flavus*, and *Pestalotia* sp. The incidence of such fungi may be at some stable level around the state. The results over both years were very consistent for some fungi. For example, the average mean maximum incidence for *C. parasiticum* was 32.6% in 1995 and 32.5% in 1996.

There were fungi for which the incidence varied considerably between 1995 and 1996. In some cases, this was probably the result of experimental error where more experience during the second year led to better identification. For example, *Blakeslea trispora* was found in 70% of all fields in 1996, but was not identified in 1995. In all likelihood, it had been grouped with the "*Choanephora*-like" fungi in 1995. There were other examples where the incidence of a fungus was considerably different between the two years. Two examples were *Thielavia terricola* and *Zygorhynchus* sp. This change could have been the result of the variation among fields from year-to-year.

When the results found in Table 3-8 are compared to those found in Table 3-9, those fungi that were most commonly isolated across an entire season were also the most commonly isolated fungi during the earliest part of the season. These fungi included *Fusarium* spp., *Penicillium* spp., *Trichoderma* spp., *M. phaseolina*, and *A. niger*. Other fungi, for example *N. vasinfecta*, *C. parasiticum*, and *Phomopsis* sp., were much less common earlier in the season than they were later in the season. This was an indication that composition of the community of soilborne fungi changes over time. Also fungi that were commonly isolated from the seedlings, for example *Fusarium* spp. and *Penicillium* spp., had a greater incidence later in the season. As the plants aged the diversity and abundance of the soilborne fungi increased.

In Table 3-10, the percentage of fields from which a fungus was isolated is presented to examine the possibility that some fungi are more common in specific areas of Florida than others. For many fungi, there did not appear to be

a relationship between the different regions of the state and incidence. For example, *R. solani*, *M. phaseolina*, *N. vasinfecta*, *Fusarium* spp., and *Trichoderma* spp. were found in all fields that were sampled across the state. There were relationships between the incidence of other fungi and the region of the state. For example, *S. rolfsii* appeared most frequently in Jackson County and less frequently in Levy and Suwannee Counties. A sterile white basidiomycete was not found in either Santa Rosa or Jackson County, but was found in the other three regions. The important pathogen *C. parasiticum* was isolated with much greater frequency in Santa Rosa and Jackson Counties than it was in the other regions. It was not isolated from fields in Alachua and Columbia Counties. Likewise, *Cylindrocladiella* sp. was found exclusively in Santa Rosa County. *Torula* sp. was not found in the Panhandle, while the incidence of *Pythium* spp., *Cunninghamella* sp., and *L. theobromae* was the lowest in Levy County. Part of this may be due to the very sandy soil present in Levy County and the excellent rotation system used by some of the growers.

Of the 48 genera of fungi that were isolated from peanut during this study, the majority was not considered causal agents of soilborne diseases. A few of these genera, including *Alternaria, Colletotrichum, Choanephora, Leptosphaerulina, Pestalotia* (*Pestalotiopsis*), and *Phoma*, contain species that have been reported to be foliar pathogens of peanut (46, 161, 162, 170, 171). When fungi isolated from the field study were inoculated into five-week-old-plants that had been wounded, the majority were not pathogenic to the host (Table 3-11). Those that were pathogenic included *C. parasiticum*, *Phomopsis* spp., *A.*

niger, *R. solani*, *S. rolfsii*, and *L. theobromae*. These fungi are known to be pathogenic to peanut (9, 31, 123, 138, 143, 153, 172). *Phomopsis* sp., a known foliar pathogen, was able to cause expanding lesions on the stems under experimental conditions. However, in a later study involving plants inoculated at different ages and growth stages, *Phomopsis* sp. did not cause any disease symptoms. *Cylindrocladium parasiticum*, the causal agent of the important disease Cylindrocladium black rot, was only a weak pathogen and caused little disease in the study with five-week-old plants. There appears to be wide variation in the pathogenicity of isolates of *C. parasiticum,* since in the later study a different isolate of the fungus was very virulent on plants of all ages. As might be expected, *S. rolfsii*, the causal agent of southern stem blight, was a virulent pathogen with the ability to kill mature plants. *Lasiodiplodia theobromae* was the most virulent of the fungi used in any of the screening studies with wounded plants. This pathogen killed almost all of the plants into which it was inoculated, and it killed them faster than either *S. rolfsii* or *C. parasiticucm.* Four fungi, a sterile white basidiomycete, *M. phaseolina, N. vasinfecta, and Fusarium* spp., which are reported pathogens of peanut, did not produce symptoms more severe than localized lesions in this experiment with mature plants (18, 71, 122, 141, 167). In a study involving maize and *Fusarium moniliforme* Sheldon, a pathogen of maize, researchers found that this fungus could exist within the host without ever causing symptoms (11). In symptomless infected plants, the fungal hyphae were intercellular only, but in plants with symptoms of disease, the hyphae were observed to be both intercellular and intracellular. These observations may help

to explain the asymptomatic presence of weak pathogens in the tissue of the peanut plants.

The second study was designed to determine how the age of a peanut plant affected the pathogenicity of specific isolates. The fungi that were included in this study were those that had been reported to be potentially pathogenic to peanut, including a fungus from the genus *Cylindrocladiella* (51). Though most of these fungi were included in the general study where mature plants were inoculated, the objective of this experiment was to determine if the pathogenicity of the fungal isolates was related to the growth stage of the host at the time of inoculation. No disease symptoms were observed in plants inoculated with *Phomopsis* sp., *Cylindrocladiella* sp., *R. solani*, a sterile white basidiomycete or *M. phaseolina* (Table 3-12). *Cylindrocladiella* sp. was a weak pathogen when inoculated in peanut by Crous (51). In the current study, it was not associated with any disease symptoms. Interestingly, this fungus was only isolated in Santa Rosa County and in fields with a history of problems with Cylindrocladium black rot. The sterile white basidiomycete did not produce any disease symptoms, and this supports work done by Bell and Sumner (18). It is unclear why disease did not develop in wounded plants, especially young plants, inoculated with *R. solani*. *Rhizoctonia solani* is an important and common pathogen of peanut and causes both seedling blights and limb rots, and has been linked to pod rot (31, 55). It may be that the isolate used in this study lacked virulence or perhaps the conditions at the time of inoculation were not adequate for the development of disease. Finally, no disease symptoms were observed in plants inoculated with

M. phaseolina. *Macrophomina phaseolina* is the causal agent of charcoal rot of peanut that is reported to be most severe under hot and dry conditions (122). This fungus was not associated with any disease symptoms either in the field or in the greenhouse throughout this research. The fungus was also inoculated into plants grown in potting mix with a moisture-content near wilt levels (data not presented). No disease symptoms were observed.

Fusarium spp. and *N. vasinfecta* are known pathogens of peanut, but are considered of minor importance (71, 141). Cannon and Hawksworth (39) referred to *N. vasinfecta* as "most probably a weak pathogen of roots causing little crop loss, though it may have significant effect with other pathogens." Both of these fungi are commonly isolated from peanut grown in Florida. *Fusarium* sp. was associated with necrosis in 50% of the seedlings that were inoculated, and was also associated with wilted and dying plants inoculated 51 days after planting. *Neocosmospora vasinfecta* was associated with necrosis and death in young plants after inoculation. Because these fungi are recovered commonly from peanut plants, it is unlikely that they are serious problems by themselves, though this experiment shows that they can cause severe symptoms under some conditions. However, they may act in some sub-lethal capacity that reduces yield. They may also interact with other pathogens and produce more severe disease complexes.

The most virulent pathogens evaluated over the range of growth stages included *C. parasiticum, A. niger, S. rolfsii,* and *L. theobromae*. Plants at all five ages that were inoculated with *A. niger* were killed, though *A. niger* was most

virulent on the youngest seedlings. *Sclerotium rolfsii* was associated with disease symptoms at all ages, though none of the youngest plants were killed. Severe symptoms were associated with all ages of the host, but fewer of the older plants were affected. The most virulent pathogens were *C. parasiticum* and *L. theobromae*. These pathogens killed most or all of the plants regardless of age at the time of inoculation. Plants that were inoculated with *L. theobromae* were killed more quickly than were any of the other plants.

Because *L. theobromae* was frequently isolated from peanut, it was surprising that Diplodia collar rot was not a more serious problem in the state. In a study by Phipps and Porter (139), there was variation in the pathogenicity of isolates of *L. theobromae* and the fungus could be isolated from asymptomatic tissue. Also, the inoculation of wounded plants with fungal isolates to evaluate pathogenicity was artificial. To create a wound in the plant and then to inoculate it with a pathogen maximized the potential for disease and minimized the ability of healthy tissue to inhibit infection. A more realistic, and natural, evaluation would have been to expose healthy peanut plants to soil that had been infested with the soilborne fungi. Fungi, such as *L. theobromae*, that caused severe symptoms in wounded plants might have had difficulty colonizing these plants and produce less severe disease. However, because the fungi in these studies had been isolated from the tissue of peanut plants, it was already known that they could colonize peanut tissue under some conditions. The virulence or avirulence of these fungi after they had infected the plant was an objective to be studied. Some fungi caused little or any symptoms on the plant, although the

wounded plants and environmental conditions in this study were optimal fro the development of disease.

Temperature has been shown to affect disease development in many pathosystems (40, 166). In this study, young peanut plants were inoculated with isolates of select fungi and then incubated at 21, 27, and 32 °C. No disease symptoms developed in those plants inoculated with *M. phaseolina*. The only disease that developed in those plants inoculated with *N. vasinfecta* occurred at the highest temperature. Severe symptoms occurred for some plants inoculated with *Fusarium* sp. at both 21 and 27 °C. Plants inoculated with *L. theobromae* died when incubated at all temperatures. Disease severity was greater in those plants inoculated with *S. rolfsii* and incubated at 27 and 32 °C than it was in plants incubated at 21 °C. Severe symptoms were associated with the lower temperature, though the plants were able to survive through the length of the study. Plants inoculated with *C. parasiticum* remained apparently healthy when incubated at 32 °C while the most severe symptoms of the fungus were associated with the coolest temperature. This is supported by research in which a soil temperature of 25°C was most conducive for the development of Cylindrocladium black rot, while no disease developed in soil at a temperature of 35 °C (137, 156).

Of the fungi that that were isolated from peanut in this study, at least four genera have been documented to include potential biocontrol agents. These genera include *Trichoderma, Gliocladium, Zygorynchus*, and *Chaetomium* (35, 36, 37, 61, 134, 159, 182). In this study, *Trichoderma* sp. isolated from peanut

appeared to parasitize several pathogens for space and nutrients when grown *in vitro*. These pathogens included *R. solani, M. phaseolina, N. vasinfecta,* an isolate of *C. parasiticum*, and *S. rolfsii*. *Chaetomium* sp. inhibited the growth of *Fusarium* sp., *A. niger*, *R. solani*, *M. phaseolina*, *N. vasinfecta*, and some isolates of *C. parasiticum* and *S. rolfsii*. *Zygorhynchus* sp. did not affect the growth of pathogens when grown in competition on agar plates. *Trichoderma harzianum* Rifai has been studied for possible use in the biological control of a number of soilborne fungal pathogens, including *Fusarium oxysporum, S. rolfsii, P. myriotylum*, and *R. solani* (53, 159, 182). In agar culture, *researchers found that T. harzianum was pathogenic to S. rolfsii but not to R.* solani or *P. myriotylum*, though other researchers have reported inhibition of these pathogens as well (182). The use of *T. harzianum* in the field to control southern stem rot on peanut was unsuccessful, possibly from the short period of activity of the inoculum (53).

Researchers were able to reduce infection of apple seedlings by *Venturia inaequalis* (Cke.) Wint. by spraying them with suspensions of ascospores and culture extracts of *Chaetomium globosum* Kunze: Fr. (61). The researchers tentatively identified the antibiotic chetomin in culture extracts and found that increased production was related to antagonism to *V. inaequalis*. Any further work on the *Chaetomium* sp. isolated from peanut should determine if chetomin or a related compound is present in the pink pigment that is produced by the fungus when grown on APDA.

The final value of the observations that some fungi, such as *Trichoderma* sp. and *Chaetomium* sp., were antagonistic to known soilborne pathogens of peanut would require more rigorous evaluations. These evaluations would include pot studies where unwounded peanut plants would be exposed to the antagonistic and pathogenic fungi in raw soil. If the presence of the antagonistic fungi was beneficial to the peanut plants in these pot studies, then further studies would be necessary in the field.

Conclusions

Forty-eight genera of fungi were isolated from peanut plants grown in Florida. The incidence of these genera ranged from abundant to rare. The most common fungi were spread across the production regions of the state; however some important fungi, such as *C. parasiticum*, were more commonly isolated in the western parts of the state.

The majority of the fungi that were isolated are not likely to cause soilborne diseases in peanut. Of the fungi that are reported in the literature to be pathogenic, no disease symptoms, even in wounded plants, were observed for *M. phaseolina*, a sterile white basidiomycete, or *Cylindrocladiella* sp. *Fusarium* sp. and *N. vasinfecta* caused severe disease symptoms under some conditions. *Rhizoctonia solani* was pathogenic occasionally. *Lasiodiplodia theobromae, A. niger*, *S. rolfsii*, and *C. parasiticum* were the most virulent pathogens, though there could be variation in pathogenicity among isolates. Two fungi, *Trichoderma* sp., and *Chaetomium* sp., were antagonistic on plates of agar to pathogens that infect peanut.

CHAPTER 4
VARIABLES RELATED TO INCIDENCE OF SOILBORNE FUNGI

Introduction

In a survey of peanut fields across the production areas of Florida in 1995 and 1996, soilborne fungi from more than 48 genera were isolated. Soilborne fungi associated with the production of peanuts may be affected by many factors that can vary from field to field and in response to practices of the grower. Some of these factors include crop rotation, field cultivation, cultural practices that modify the soil temperature, populations of plant parasitic nematodes, the use of fungicides, and irrigation (16, 17, 23, 27, 32, 33, 34, 59, 60, 64, 70, 73, 83, 109, 112, 123, 125, 145, 148, 154, 156, 157, 165).

As the season progresses, the growth stage of the host and environmental conditions will change. Studies have been done to explore the changing diversity of fungi based upon crop age and growth stage. Mueller et al. (126) followed the incidence of soilborne fungi in soybean roots during an entire season and found that the incidence of specific fungi changed as the season progressed. A similar study was conducted on corn (185). In this latter study, five different communities of fungi were identified in conjunction with the particular growth stages of the plants that were sampled. Dawson and Bateman (62) found that the diversity of the fungal communities associated with the root

and shoot bases of winter barley and winter wheat differed among samples collected in January and in June.

The objective of the research presented in this chapter was to explore how variables within a field or among fields affected the incidence of soilborne fungi. Factors that will be addressed here include an assessment of the relationship between the incidence of fungi in the roots, pods, pegs, and hypocotyls of peanut plants and soil fertility, populations of pathogenic nematodes, planting dates, crop rotation, the incidence of other fungi, yield, harvest grade, the use of pesticides, host growth stage, and the part of the plant from which isolations are made. Such information should provide a better understanding of fungal ecology in an agricultural environment and also provide information to improve strategies for disease control.

Materials and Methods

Site Selection

The peanut fields sampled for the results presented in this chapter are described in Tables 3-2, 3-3, and 3-4. The relationship between the incidence of selected fungi in plants and different field variables was evaluated in 15 commercial fields in 1995 and nine commercial fields in 1996.

Isolation of Soilborne Fungi

Fungi were isolated from the belowground parts of the peanut plant as described in the materials and methods section in Chapter 3.

Assessment of Soil Fertility

Soil samples were collected from each sampling site soon after the planting date. Soil samples were taken to a depth of 12.7 cm. Two soil samples were obtained from within the seedbed near each plant that was sampled on this date; 40 samples were collected from a single field. The samples from a single field were combined and then air-dried. The dried samples were sifted through a mesh screen to remove plant debris and stones, and then analyzed for pH and concentrations of calcium, phosphate, potassium, and magnesium ions. The analyses were done using the following methods at the IFAS Extension Soil Testing Laboratory and Analytical Research Laboratory at the University of Florida in Gainesville.

Soil pH

The activity of the hydronium ions in the soil samples was evaluated by measuring the pH. Twenty cubic centimeters of soil were poured into a 90-mL plastic cup. Forty milliliters of pure water were added to the cup using an automatic pipet. The mixture was stirred with a glass rod and allowed to stand for at least 30 minutes but not longer than 2 hours. While the mixture was being stirred, the pH of the solution was measured using a combination electrode (Orion model 915600) and pH meter (model 601A, Beverly, MA).

Nutrient Concentrations

The concentrations of phosphorus, potassium, calcium, and magnesium were measured in each soil sample by the staff at the IFAS Extension Soil Testing Laboratory as follows. The Mehlich-1 Extracting solution (0.0125M

H_2SO_4 and 0.050M HCl) was made by adding 13.9 mL of concentrated sulfuric acid and 83 mL of concentrated hydrochloric acid to 16 L of pure water in a plastic carboy and then this solution was diluted to a final volume of 20 L. Four cubic centimeters of the sample were placed into a 50-mL extracting bottle. Twenty milliliters of the Mehlich-1 extracting solution were pipetted into the extracting bottle and then shaken on a reciprocating shaker. After 5 minutes, the sample was filtered through a Roger's Custom Lab 620, 11-cm filter paper into a 90-mL plastic cup. The filtrate was transferred to a 20-mL scintillation vial for analysis using an inductively coupled argon plasma spectrometer (ICP model 61E Thermo Jarrell Ash Corporation, Franklin, MA). The concentration of the elements was reported by the laboratory in terms of mg per kg of soil (ppm).

A second set of soil samples was taken from each field after gypsum had been applied near the time when the plants entered the pegging stage of development. These soil samples were taken to a depth of 7.6 cm to include primarily that volume of soil in which pods develop. This region will be referred to as the "pegging zone." These samples were again combined, air dried, sifted through a mesh screen, and then submitted for analysis.

Assessment of Levels of Pathogenic Nematodes

Soil and root samples were collected as the peanut plants entered the early reproductive growth stages. Soil samples for the analysis of nematode populations were collected from the pegging zone as described for the soil samples in the preceding section. These samples were refrigerated and submitted for an assessment of the populations of parasitic nematodes. In 1996,

a second sample was taken near the end of the season from each site. This sample was submitted, along with root and pod tissue, for analysis at the Nematode Assay Laboratory at the University of Florida in Gainesville. The soil and tissue samples were collected in the vicinity of those plants sampled for fungal isolations.

Protocol to Process Soil Samples for Nematodes

After all large pieces of plant material were removed, the field soil was thoroughly mixed in a plastic bag. A 100-mL beaker was filled with tightly packed soil. The soil was emptied into a standard kitchen strainer that was nested in a 2-L stainless steel pitcher. The soil was washed through the strainer with a forceful stream of water and then the strainer was removed. The wash was allowed to stand for 30 seconds to let the sand settle, and was then decanted slowly through a 400-mesh sieve. Soil and nematodes were washed from the sieve into a 100-mL centrifuge tube with a fine stream of water from a wash bottle. The centrifuge tube was filled to within 0.64 cm from the top. The tube was then centrifuged at 2200 RPM for 3 minutes. The supernatant was discarded without disturbing the plug at the bottom of the tube. The centrifuge tube was filled half way with a sucrose solution (454 g/1 L water), plugged with a rubber stopper, and then shaken to resuspend the pellet. The tube was filled to within 1.27 cm from the top with additional sucrose solution and centrifuged as before. Nematodes were thus suspended in the sucrose solution, which was poured onto a small 500-mesh sieve. The nematodes were washed through a funnel into a clean 50-mL centrifuge tube and placed for storage in the

refrigerator. All utensils were washed to prevent cross contamination of samples.

Protocol to Process Tissue Samples for Nematodes

Soil was rinsed from tissues from roots, hypocotyls, pods, and pegs and the tissue was then dried as much as possible using a paper towel. Tissue samples were then weighed. And then blended on the lowest setting in 300 mL of water. The resulting slurry was poured through a 500-mesh sieve. Nematodes were washed from the sieve onto a coffee filter and moved to a clean bowl of water. Samples were then left on a shelf for 24 hours.

The samples were then assessed for the number of plant parasitic nematodes that were present. These included species of *Meloidogyne, Belonolaimus, Pratylenchus, Hoplolaimus, Helicotylenchus, Trichodorus, Heterodera, Tylenchorhynchus, Criconemoides, Tylenchus,* and *Peltamigrates.* Of these genera, *Meloidogyne* and *Pratylenchus* pose the greatest threat to peanut production in Florida. An extension nematologist then provided a diagnosis. A rating of "1" indicated that the numbers of nematodes was high enough to cause serious injury to the crop. A rating of "2" indicated that the levels of nematodes could be high enough to injure the crop. A rating of "3" indicated that the nematodes were below levels believed to be damaging to a peanut crop.

Fungal Incidence Versus Crop Age and Plant Part

This experiment was based upon the results from the survey of commercial fields in 1995 and 1996. The incidences of different soilborne fungi

in the commercial fields were analyzed using two statistical techniques, analysis of variance with mean separation, and correspondence analysis.

Analysis of Variance

Data were analyzed using a split-plot model. The individual commercial fields were designated as the experimental blocks. Whole plot treatments were the ages or growth stages at the time of sampling. Because of the many different planting dates, distance involved in travel, and time required to process samples, it was not possible to sample each field at identical ages as measured in "days after planting." However, the crop ages at the time of sampling and growth stages for all sites fit within five windows as listed in Table 4-1. Thus the values of the whole plot treatments varied between "1" and "5," where "1" had an average age of 20 days after planting and a vegetative growth stage and "5" had an average age of 129 days after planting and a growth stage of harvest maturity. Subplot treatments were the part of the plant from which the fungi were isolated. These parts included the total plant (isolation of the fungus from any part of a given plant), hypocotyls, roots, pegs, and pods. Mean separation was done using Duncan's multiple range test with significance at the $\alpha = 0.1$ level. Because the different windows of sampling dates represented quantifiable levels of a treatment, use of means separation was inappropriate to determine differences in the incidence of a fungus over time. Linear regression would be more appropriate, but was not used because of variability in sampling for soilborne fungi. The means of fungal incidences on peanut plant at the progressive sampling dates calculated with analysis of variance were used to

Table 4-1. Range of crop ages and growth stages of peanut for sequential sampling dates during 1995 and 1996.

Sampling trip	Crop age (days after planting)	Average age (days)	Growth stage[y]
1	5-35	20	vegetative
2[z]	39-70	53	flowering to Pod
3	65-94	82	beginning to full seed
4	87-122	106	full seed to beginning maturity
5	112-143	129	harvest maturity

[y] Growth stages of peanut adapted from Boote (25).
[z] Sampling trip 2 contained one field at the "beginning seed" stage; sampling trip 3 contained two fields at the stage of beginning maturity.

describe trends observed over the season. Means separation techniques were appropriate to determine differences in the incidence of a fungus on different parts of the plant.

Correspondence Analysis

The same data analyzed with analysis of variance was also evaluated using a statistical procedure referred to as correspondence analysis. Correspondence analysis is based upon the chi-squared test and has been described as an "exploratory" technique that can provide the basis for more formal hypothesis testing (Mr. J. Harrison, consultant, Institute of Food and Agricultural Sciences Statistics Department, personal communication). Correspondence analysis is well suited for categorical data and has been used to evaluate the relationship between soilborne fungi and root disease in soybean and soilborne fungi in the peanut rhizosphere in Senegal (69,181). The results of this analysis can be presented in the form of a two dimensional plot. Data points that lie closest to the origin are least affected by some variable, such as crop age, plant part, or plant health, while those farthest from the origin are most affected. Points on the plot that lie closest together are more related to each other than are points that lie farther apart. Distances between plots are not defined by this technique. The statistical significance between two points on the plot cannot be determined, thus the interpretation of results from correspondence analysis is less exact than from analysis of variance. The greatest benefit from correspondence analysis is that it allows one to simplify a very complex set of data and to make observations about the potential

relationships between factors. The author circled groups of closely related points on the plots derived from correspondence analysis to facilitate interpretation by the reader.

Results

Evaluation with Pearson's Correlation Coefficient

The concentrations of phosphorus, magnesium, potassium, and calcium were determined for each soil sample. The pH of each soil sample was also determined, as were the numbers of plant parasitic nematodes. Soil fertility factors were assessed both early in the season and after the pegging growth stage when gypsum would have been added to the soil. Correlation analysis was used to detect possible relationships between the incidence of selected fungi and these field variables.

The fungi studied with correlation analysis were *Fusarium* spp., *Rhizoctonia solani, Pythium spp., Aspergillus flavus, A. niger, Cylindrocladium parasiticum, Sclerotium rolfsii, Phomopsis* sp., *Macrophomina phaseolina, Trichoderma* spp., *Neocosmospora vasinfecta, Chaetomium* sp. *Rhizopus* spp., and *Lasiodiplodia theobromae.* These fungi were included based upon their potential as soilborne pathogens of peanut, their possible role in biological control, or, in the case of *Phomopsis* sp., its interesting pattern of isolation and association with the pegs of the peanut plant.

The factors against which the data for each fungus were correlated also included an evaluation of crop rotation for each field, the yield from each field, the grade of this yield as reported by the grower, the levels of nematodes both

early and late in the season (based on a scale of 1-3), the number of nematodes of the genera *Meloidogyne* and *Pratylenchus* that were recovered from root tissue and soil, and the calendar date of planting. Crop rotation was ranked on a scale of 1-6. A ranking of "1" indicated that peanut was planted in a field for 2 consecutive years. A ranking of "2" indicated that peanut was planted in the same field on a 2-year rotation. A ranking of "3" indicated that peanut was planted in a 3-year rotation. A ranking of "4" or "5" indicated a 4- or 5- year rotation. A ranking of "6" indicated that peanut was not grown in a field for at least the preceding 6 years.

Pearson's correlation coefficients were determined for the relationships between fungal incidences in 1995 and 1996 are presented as a matrix in Table 4-2. Only those coefficients with values ≥0.1 have been included. These values are significant at least at the level of p≤0.1. The incidence of *Trichoderma* spp. was negatively correlated with the incidences of *C. parasiticum* and *L. theobromae*. The incidences of *Phomopsis* sp., *L. theobromae*, and *C. parasiticum* were positively correlated with each other. The magnitude of the correlation coefficients for the incidences of *A. niger* and *L. theobromae*, *M. phaseolina* and *Fusarium* spp., *S. rolfsii* and *Fusarium* spp., *Pythium* spp. and *N. vasinfecta*, and *R. solani* and *S. rolfsii*, were small (≤ 0.37) and the coefficients had a large p-value (≤ 0.1).

Pearson's correlation coefficients are presented for the relationships between fungal incidence and field factors in Table 4-3. Again, only those coefficients with absolute values greater than 0.1 are included in the table. For

Table 4-2. Pearson's correlation coefficients[y] for incidences of selected soilborne fungi from all commercial fields that were significant and ≥ 0.1 or ≤ –0.1 in the combined 1995 and 1996 seasons.

Fungus[z]	ANI	CYL	FUS	LAS	MAC	NEOC	PMPS	PYTH	RHZC	SROL	TRIC
ANI				0.35*							
CYL				0.68***			0.60**				-0.49**
FUS					0.35*					0.37*	
LAS	0.35*	0.68***					0.59**				-0.47**
MAC			0.35*								
NEOC								0.35*			
PMPS		0.60**		0.59**							
PYTH						0.35*					
RHZC										-0.36*	
SROL			0.37*						-0.36*		
TRIC		-0.49*		-0.47**							

[y] *= p≤0.1; **= p≤0.05; ***= p≤0.001

[z] Fungi included: ANI= *Aspergillus niger*, CYL= *Cylindrocladium parasiticum*, FUS= *Fusarium* spp., LAS= *Lasiodiplodia theobromae*, MAC= *Macrophomina phaseolina*, NEOC= *Neocosmospora vasinfecta*, PMPS= *Phomopsis* sp., PYTH= *Pythium* spp., RHZC= *Rhizoctonia solani*, SROL= *Sclerotium rolfsii*, and TRIC= *Trichoderma* spp.

Table 4-3. Pearson's correlation coefficients[y] for incidence of selected soilborne fungi and field factors that were significant and ≥ 0.1 or ≤ –0.1 in both 1995 and 1996.

Variable[z]	*Aspergillus niger*	*Chaetomium sp.*	*Cylindrocladium parasiticum*	*Lasiodiplodia theobromae*	*Macrophomina phaseolina*	*Neocosmospora vasinfecta*	*Pythium* spp.	*Phomopsis* sp.	*Rhizoctonia solani*	*Rhizopus* spp.
Planting Date										
1995	0.25					0.21	0.16	0.10		0.24
1996	0.13					0.11	0.24	0.18		0.30
Rotation										
1995	-0.24			0.10						-0.27
1996	-0.13			0.11						-0.42
Yield										
1995									-0.18	
1996									-0.11	
Grade										
1995										-0.30
1996										-0.34
Early Ca										
1995		-0.10	-0.10							0.14
1996		-0.17	-0.13							0.27
Late Ca										
1995									-0.14	
1996									-0.11	
Early Mg										
1995				0.23		0.17		0.14		
1996				0.26		0.14		0.20		
Late Mg										
1995	0.36			0.24						
1996	0.14			0.16						
Early K										
1995			0.10		0.16			0.11		
1996			0.15		0.15			0.11		
Late K										
1995	0.23	0.12	0.13	0.14	0.14	0.15				
1996	0.26	0.13	0.14	0.13	0.30	0.13				

Table 4-3 continued.

Variable	*Aspergillus niger*	*Chaetomium* sp.	*Cylindrocladium parasiticum*	*Lasiodiplodia theobromae*	*Macrophomina phaseolina*	*Neocosmospora vasinfecta*	*Pythium* spp.	*Phomopsis* sp.	*Rhizoctonia solani*	*Rhizopus* spp.
Early P										
1995							0.16			
1996							0.29			
Late P										
1995							0.15			
1996							0.27			
Early pH										
1995							0.18			
1996							0.19			
Meloid										
Early root										
1995		-0.13		-0.11		-0.26				
1996		-0.12		-0.15		-0.22				
Pratyl.										
Early root										
1995										0.18
1996										0.15
Pratyl										
Early soil										
1995	0.14									
1996	0.16									

[y] The coefficients in this table are significant at $p \leq 0.0001$

[z] The variables include: Early= results based on sampling during vegetative growth; Late= results based on sampling after pegging began; Ca= calcium; Mg= magnesium; K= potassium; P= phosphorus; *Meloid*= *Meloidogyne* spp.; *Pratyl*= *Pratylenchus* spp.

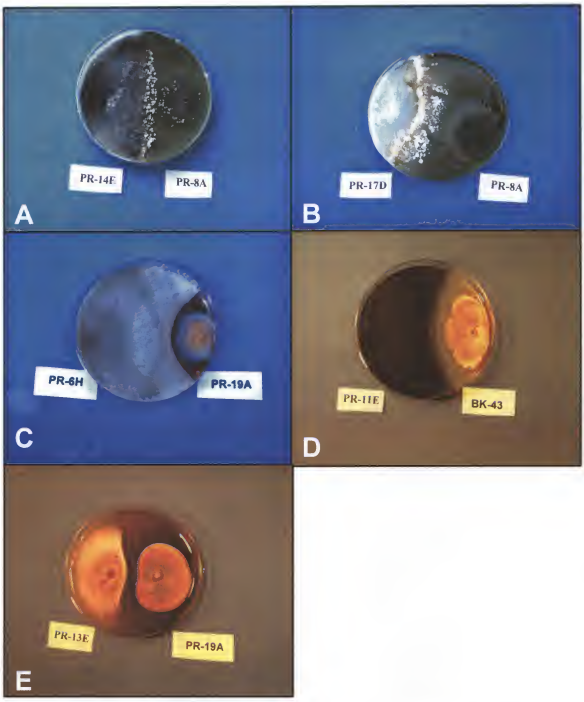


Figure 3-3. Interactions between fungi on acidified potato dextrose agar. A. "Barrier" interaction between *Lasiodiplodia theobromae* (PR-14E) and *Trichoderma* sp. (PR-8A). B. "Overgrowth" of *Sclerotium rolfsii* (PR-17D) by *Trichoderma* sp. C. "Inhibition" *of Rhizoctonia solani* (PR-6H) by *Chaetomium* sp. (PR-19A). D. Inhibition of *Macrophomina phaseolina* (PR-11E by *Eupenicillium* sp. (BK-43). E. "Avoidance" of *Neocosmospora vasinfecta* (PR-13E) from *Chaetomium* sp. (PR-19A).

this information, the data from individual years was analyzed separately to determine if correlation between a field factor and the incidence of a fungus that was detected in 1995 was repeated in 1996. To reduce the possibility that the correlation between the two variables was coincidental, only those results that were consistent between 1995 and 1996 are presented in this table.

The incidences of a number of fungi were positively correlated with the date that the peanuts were planted (Table 4-3). These fungi included *A. niger*, *N. vasinfecta*, *Pythium* spp., *Phomopsis* sp., and *Rhizopus* spp. None of the fungi were negatively correlated with the planting date. The incidences of two fungi, *A. niger* and *Rhizopus* spp., were negatively correlated with improved crop rotation. The incidence of *L. theobromae* was positively correlated with improved crop rotation. The incidence of *R. solani* was negatively correlated with the harvested yields that were reported by the growers; *Rhizopus* spp. was negatively correlated with the reported grades of the harvested peanuts.

A number of fungi were positively correlated with concentrations of Mg^{2+}, K^{+}, P^{3+}, or the activity of the hydronium ions in the soil (Table 4-3). *Lasiodiplodia theobromae*, *N. vasinfecta*, *Phomopsis* sp., and *A. niger* were positively correlated with the concentration of Mg^{2+} in the soil. *Aspergillus niger*, *Chaetomium* sp., *C. parasiticum*, *L. theobromae*, *M. phaseolina*, and *N. vasinfecta* were positively correlated with the concentration of K^{+} in the soil. The incidences of *Pythium* spp. were positively correlated with the concentration of P^{3+} and the activity of the hydronium ions in the soil. Several fungi, *Chaetomium*

sp., *C. parasiticum*, and *R. solani*, were negatively correlated with the concentration of Ca^{2+} in the soil.

There were several instances where significant correlation between a factor and a fungus occurred during one season, but not the other and were thus not included in Table 4-3. For example, the incidence of *R. solani* was negatively correlated (-0.16; $p \leq 0.0001$) with crop rotation and positively correlated with the quantity of juveniles of *Meloidogyne* sp. recovered from root tissue at pegging time (0.11; $p \leq 0.0001$) in 1995. These trends were not observed in 1996. Also, in 1995, the incidence of *A. niger* was negatively correlated with the reported grade of the harvested peanuts (-0.38; $p \leq 0.0001$). The incidence of *A. flavus* was negatively correlated with reported grade (-0.28; $p \leq 0.0001$), and with crop rotation (-0.13, $p \leq 0.0001$) during the same year. In 1996, negative correlations were observed between the incidence of *Pythium* spp. and crop rotation, yield, and reported grade (-0.17, -0.10, and –0.21, respectively; $p \leq 0.0001$).

Some of the fungi included in the correlation analysis were not isolated from 100% of the commercial fields (Table 3-9). The relationships between yield, grade, and fungal incidence were calculated again for those fungi not found in all fields with only the data from the fields in which the fungi were isolated. From these subsets of fields (1995+1996), the incidences of *S. rolfsii, L. theobromae*, and *Pythium* spp. still were not significantly correlated with yield or grade. However, when those fields from which *C. parasiticum* was isolated were considered, there was a significant and negative correlation between the

incidence of this pathogen and the grade of the harvested peanut. Pearson's correlation coefficient for this relationship was -0.71353 with p=0.0205.

Variation in Fungal Incidence with Time and Plant Part

The main effects and interactions, as calculated using analysis of variance, between the incidences of eight fungi, the time of sampling, and the plant parts are presented in Table 4-4. The results for each fungus were calculated using data from only those fields in which the specific fungus was recovered. For example, *A. niger* was recovered from all commercial fields in 1995 and 1996, so data from 15 fields were analyzed for 1995 and nine fields for 1996. *Cylindrocladium parasiticum* was found in fewer fields, so the results for this fungus were based on a subset of the commercial fields from both years.

In both 1995 and 1996, the incidences of *A. niger*, *A. flavus*, *C. parasiticum*, *L. theobromae*, *N. vasinfecta*, *Pythium* spp., and *R. solani* were significantly different in a least one field, during at least one sampling trip, and in at least one of the parts of the peanut plant (hypocotyls, roots, pegs, or pods) from the incidences in other fields, on other sampling trips, and in other parts of the plant (Table 4-4). In one or both of these years, there was a significant interaction for the incidences of these fungi between the field that was sampled and the time that the plants were sampled and between the time that the plants were sampled and the part of the plant from which a fungus was isolated. In 1996, there was no significant difference in the incidence of *S. rolfsii* over the different sampling dates and no significant interaction between the time of the sampling trip and the part of the plant from which this pathogen was isolated.

Table 4-4. Main effects and interactions of sampling trip and plant part on recovery of eight soilborne fungal pathogens of peanut from commercial fields in Florida during 1995 and 1996.

Source of variation	Mean Squares							
	df (1995)	*Aspergillus niger*	df (1996)	*Aspergillus niger*	df (1995)	*Aspergillus flavus*	df (1996)	*Aspergillus flavus*
Block[w]	14	25.6****[x]	8	13.4****	14	5.18****	8	3.30****
Trip[y]	4	12.2****	4	3.6****	4	0.54****	4	0.51****
Block X Trip	54	3.4****	31	3.9****	54	0.27****	31	1.58****
Part[z]	4	11.2****	4	10.0****	4	1.28****	4	2.00****
Trip X Part	14	0.4****	14	0.5****	14	0.14****	14	0.09 ns
C.V.	89.8		93.5		298.8		235.0	
		Cylindrocladium parasiticum		*Cylindrocladium parasiticum*		*Lasiodiplodia theobromae*		*Lasiodiplodia theobromae*
Block	6	1.00***	4	2.56****	11	1.40****	7	5.48****
Trip	4	1.48****	4	3.57****	4	2.04****	4	3.37****
Block X Trip	20	0.41****	15	0.79****	43	0.65****	27	0.56****
Part	4	0.40****	4	0.44****	4	0.95****	4	3.04****
Trip X Part	14	0.06 ns	14	0.10 ns	14	0.20****	14	0.28****
C.V.	354.2		261.3		340.5		232.2	
		Neocosmospora vasinfecta		*Neocosmospora vasinfecta*		*Pythium* spp		*Pythium* spp.
Block	14	9.07****	8	3.58****	3	0.32****	2	0.68****
Trip	4	14.88****	4	6.88****	4	0.23****	4	0.11*
Block X Trip	54	1.32****	31	1.19****	11	0.42****	8	0.30****
Part	4	27.18****	4	32.89****	4	0.14****	4	0.14**
Trip X Part	14	1.32****	14	0.92****	14	0.05****	14	0.04 ns
C.V.	138.2		133.8		464.1		445.8	
		Rhizoctonia solani		*Rhizoctonia solani*		*Sclerotium rolfsii*		*Sclerotium rolfsii*
Block	14	2.85****	8	4.21****	5	0.03**	5	0.11****
Trip	4	2.46****	4	1.55****	4	0.08****	4	0.03 ns
Block X Trip	54	0.69****	31	0.50****	15	0.04****	19	0.06****
Part	4	12.46****	4	4.94****	4	0.03**	4	0.08****
Trip X Part	14	1.20****	14	0.38****	14	0.02**	14	0.02 ns
C.V.	189.5		206.5		964.4		736.0	

[w] Block= the commercial fields in which peanut plants were sampled.

[x] ****= $p \leq 0.0001$, ***= $p \leq 0.001$, **= $p \leq 0.01$, *= $p \leq 0.05$, ns: not significant.

[y] Trip= the sequential sampling trips to each commercial field.

[z] Part= hypocotyls, roots, pegs, and pods of the peanut plant.

The mean incidences of the common fungi at each sampling date and from each part of the plant are presented in Table 4-5. The reported values are the mean percentage of plants or tissue from which the fungus was isolated on each of the five sampling dates representing different growth stages of the crop during the season. As for Table 4-4, the results were based only on the data from those fields in which a fungus was isolated during the season.

Fungi such as *Fusarium* spp., *Penicillium* spp., and *Trichoderma* spp. were more abundant during the earliest sampling date than most other fungi and were very abundant throughout the remainder of the season. The incidences of other fungi, such as *M. phaseolina, N. vasinfecta*, and *R. solani*, were lower on the first sampling date than those fungi listed above, but were abundant by the second sampling date. *Cylindrocladium parasiticum*, *Mucor spp.*, and *Phomopsis* sp., were most abundant during the second half of the season. *Alternaria* sp., *Chaetomium* sp., and *Phoma* sp. peaked prior to the end of the season, and then declined during the remainder of the season. Fungi such as *Colletotrichum* sp., *Cunninghamella* sp., *Gleosporium* sp., *Bipolaris* sp., and *Nectria* sp. were never commonly isolated and their mean incidences were below 10%.

Fungi could be isolated more commonly from some parts of the plant than from other parts. For example, *Fusarium* spp. and *M. phaseolina* were more commonly isolated from the roots and the pegs than from the hypocotyls or the pods while *N. vasinfecta* was most commonly isolated from the roots alone. *Trichoderma* sp. was isolated more commonly from the hypocotyls and roots

Table 4-5. Mean incidences of specific soilborne fungi as related to the year and time of season when plants were sampled and part of plant from which the fungus was isolated.

		Incidence of isolation (%)									
		1995					1996				
Fungus	Part	T1[v]	T2	T3	T4	T5	T1	T2	T3	T4	T5
Alternaria sp.	**Tot[w]**	**1.2 a[x]**	**34.3 a**	**44.3 a**	**13.3 a**	**15.9 a**	**0.6 a**	**26.2 ab**	**24.4 a**	**14.4 a**	**8.6 a**
	Hyp[y]	0.4 a	5.4 c	2.1 d	0.3 b	1.0 c	0.0 a	0.0 c	1.9 c	1.2 c	0.7 b
	Root	0.8 a	21.9 b	12.8 c	1.7 b	6.4 b	0.6 a	16.2 b	11.9 b	6.9 b	3.6 b
	Peg	NA	34.8 a	27.8 b	10.6 a	7.2 b	NA	22.8 ab	7.0 bc	5.7 bc	4.3 b
	Pod	NA	21.7 b	20.1 c	1.7 b	3.6 bc	NA	35.7 a[z]	11.1 b	3.1 bc	0.7 b
Aspergillus niger	**Tot**	**28.1 a**	**51.8 a**	**55.7 a**	**57.0 a**	**74.9 a**	**43.9 a**	**58.3 a**	**62.8 a**	**66.7 a**	**74.4 a**
	Hyp	20.2 b	36.0 bc	34.0 b	33.4 c	47.2 bc	32.2 b	32.8 bc	27.8 c	42.2 c	39.4 c
	Root	17.1 b	43.8 ab	32.3 b	40.1 b	49.2 bc	33.3 b	45.0 b	36.7 b	52.8 b	43.8 c
	Peg	NA	30.5 c	36.1 b	41.6 b	51.8 b	NA	31.5 c	31.6 bc	53.1 b	55.0 b
	Pod	NA	10.4 d	25.0 c	30.8 c	43.3 c	NA	27.3 c	24.3 c	35.8 c	38.1 c
Aspergillus flavus	**Tot**	**2.8 a**	**9.1 a**	**14.8 a**	**20.0 a**	**17.9 a**	**22.2 a**	**26.1 a**	**19.4 a**	**21.7 a**	**21.2 a**
	Hyp	2.0 ab	5.4 b	7.0 b	9.7 b	5.6 b	15.6 b	12.8 bc	6.1 bc	11.1 b	11.9 b
	Root	1.2 b	4.0 b	7.4 b	8.0 b	10.2 b	14.4 b	18.3 ab	12.2 b	7.2 bc	8.8 b
	Peg	NA	2.0 bc	8.9 b	6.8 b	8.7 b	NA	10.1 cd	6.8 bc	8.9 bc	8.1 b
	Pod	NA	0.0 c	6.1 b	6.2 b	7.7 b	NA	3.0 d	4.0 c	4.5 c	10.0 b
Chaetomium sp.	**Tot**	**7.4 a**	**19.4 a**	**15.1 a**	**15.8 a**	**6.2 a**	**8.1 a**	**17.5 a**	**17.5 a**	**6.9 a**	**2.1 a**
	Hyp	4.4 ab	3.5 b	3.5 b	3.5 bc	1.9 b	5.0 a	5.0 b	7.5 b	1.2 bc	0.0 b
	Root	3.5 b	4.3 b	3.5 b	1.9 c	2.0 b	3.1 a	4.4 b	5.6 b	1.9 bc	0.7 ab
	Peg	NA	19.5 a	7.0 b	4.2 bc	6.0 b	NA	15.2 a	5.0 b	0.6 c	0.7 ab
	Pod	NA	3.1 b	5.3 b	8.1 b	3.1 b	NA	5.8 b	7.6 b	3.8 b	NA

Table 4-5. Continued.

		Incidence of isolation (%)									
		1995					1996				
Fungus	Part	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5
Choanephora cucurbitarum	**Tot**	**0.0 a**	**0.0 a**	**4.2 a**	**20.4 a**	**17.9 a**	**0.7 a**	**12.9 a**	**8.6 a**	**15.0 a**	**7.8 a**
	Hyp	0.0 a	0.0 a	0.4 b	3.3 b	5.5 bc	0.0 a	2.8 ab	2.8 ab	6.4 b	0.0 b
	Root	0.0 a	0.0 a	2.5 ab	7.9 b	7.3 bc	0.7 a	8.6 ab	2.8 ab	5.0 b	2.1 b
	Peg	NA	0.0 a	1.7 ab	16.3 b	9.0 b	NA	10.5 ab	5.8 ab	9.3 ab	4.3 ab
	Pod	NA	0.0 a	0.4 b	3.8 b	2.1 c	NA	2.3 b	0.0 b	2.1 b	2.1 b
Cladosporium sp.	**Tot**	**0.0 a**	**14.6 a**	**2.5 a**	**1.5 a**	**1.6 a**	**0.6 a**	**3.1 a**	**0.6 a**	**1.9 a**	**3.6 a**
	Hyp	0.0 a	1.5 b	0.0 b	0.0 b	0.0 b	0.0 a	0.6 a	0.0 a	0.06 ab	0.7 ab
	Root	0.0 a	4.0 b	0.0 b	0.0 b	0.8 ab	0.6 a	1.2 a	0.6 a	0.0 b	2.1 ab
	Peg	NA	12.7 a	0.0 b	1.0 ab	0.8 ab	NA	2.3 a	0.0 a	0.6 ab	1.4 ab
	Pod	NA	5.7 b	2.5 a	0.5 ab	0.0 b	NA	3.0 a	0.0 a	0.6 ab	0.0 b
Colletotricum sp.	**Tot**	**3.6 a**	**4.5 abc**	**1.1 a**	**0.6 a**	**6.7 a**	**2.5 a**	**0.8 a**	**3.3 a**	**5.0 a**	**6.0 a**
	Hyp	0.6 a	0.0 c	0.0 b	0.0 a	0.0 a	0.0 a	0.0 a	0.0 b	0.0 b	0.0 b
	Root	3.0 a	1.1 bc	0.0 b	0.0 a	0.0 a	0.0 a	0.0 a	0.0 b	0.0 b	0.0 b
	Peg	NA	4.8 ab	0.0 b	0.6 a	4.8 a	NA	1.9 a[z]	2.5 a	3.4 a	5.0 ab
	Pod	NA	5.7 a[z]	1.1 a	0.0 a	3.8 a	NA	0.0 a	0.8 ab	2.5 ab	1.0 ab
Cunninghamella sp.	**Tot**	**0.0 a**	**2.5 a**	**1.3 a**	**9.2 a**	**3.4 a**	**5.0 a**	**7.5 a**	**0.0 a**	**5.0 a**	**3.8 a**
	Hyp	0.0 a	1.3 ab	1.3 a	6.3 a	2.1 ab	3.8 a	3.8 ab	0.0 a	2.5 ab	3.8 a
	Root	0.0 a	1.3 ab	0.4 a	1.7 b	0.7 b	1.2 a	5.0 ab	0.0 a	1.2 b	0.0 b
	Peg	NA	0.6 b	0.4 a	1.2 b	0.7 b	NA	0.0 b	0.0 a	0.0 b	0.0 b
	Pod	NA	0.0 b	0.0 a	0.8 b	0.7 b	NA	NA	0.0 a	1.2 b	0.0 b
Curvularia spp.	**Tot**	**1.2 a**	**6.4 a**	**14.8 a**	**11.7 a**	**11.8 a**	**1.2 a**	**8.8 a**	**13.8 a**	**11.9 a**	**10.0 a**
	Hyp	0.0 b	0.3 b	1.8 c	1.7 c	0.5 b	1.2 a	0.6 b	0.6 c	0.6 c	0.0 b
	Root	1.2 b	2.4 a	3.7 bc	3.7 bc	2.1 b	1.2 a	5.0 ab	3.8 bc	4.4 bc	1.4 b
	Peg	NA	6.0 a	7.6 b	5.5 b	9.7 a	NA	6.0 ab	10.2 ab	6.3 b	7.1 a
	Pod	NA	0.0 b	4.6 bc	2.0 c	1.0 b	NA	0.0 b	2.6 c	0.6 c	2.1 b

Table 4-5 continued.

		Incidence of isolation (%)									
		1995					1996				
Fungus	Part	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5
Cylindrocladium parasiticum	**Tot**	**1.7 a**	**0.8 a**	**10.0 a**	**19.2 a**	**18.7 a**	**3.0 a**	**0.0 a**	**8.0 a**	**33.0 a**	**26.2 a**
	Hyp	1.7 a	0.0 a	2.5 b	10.1 bc	9.3 bc	1.0 a	0.0 a	1.0 c	14.0 c	13.8 b
	Root	0.8 a	0.8 a	6.7 ab	14.2 ab	16.4 ab	3.0 a	0.0 a	5.0 ab	23.0 b	18.8 b
	Peg	NA	0.0 a	4.2 b	7.6 c	5.3 c	NA	0.0 a	3.0 bc	20.0 bc	13.8 b
	Pod	NA	0.0 a	2.5 b	9.2 bc	8.0 c	NA	0.0 a	3.1 bc	21.2 bc	13.8 b
Gleosporium sp.	**Tot**	**0.0 a**	**0.0 a**	**2.5 a**	**0.8 a**	**5.3 a**	**NR**	**NR**	**NR**	**NR**	**NR**
	Hyp	0.0 a	0.0 a	0.0 b	0.0 a	0.0 c	--	--	--	--	--
	Root	0.0 a	0.0 a	0.0 b	0.0 a	0.0 c	--	--	--	--	--
	Peg	NA	0.0 a	1.7 ab	0.8 a	4.0 ab	--	--	--	--	--
	Pod	NA	0.0 a	0.9 ab	0.0 a	1.3 bc	--	--	--	--	--
Gliocladium sp.	**Tot**	**0.0 a**	**0.0 a**	**1.0 a**	**3.0 a**	**0.0 a**	**NR**	**NR**	**NR**	**NR**	**NR**
	Hyp	0.0 a	0.0 a	0.0 a	0.0 b	0.0 a	--	--	--	--	--
	Root	0.0 a	0.0 a	0.0 a	1.0 ab	0.0 a	--	--	--	--	--
	Peg	NA	0.0 a	1.0 a	2.0 ab	0.0 a	--	--	--	--	--
	Pod	NA	0.0 a	0.0 a	0.0 b	0.0 a	--	--	--	--	--
Bipolaris sp.	**Tot**	**1.1 a**	**0.0 a**	**5.1 a**	**1.7 a**	**2.5 a**	**NR**	**NR**	**NR**	**NR**	**NR**
	Hyp	0.0 a	0.0 a	0.0 b	0.0 b	0.0 a	--	--	--	--	--
	Root	1.1 a	0.0 a	4.2 ab	0.0 b	0.0 a	--	--	--	--	--
	Peg	NA	0.0 a	0.0 b	1.7 a	1.25 a	--	--	--	--	--
	Pod	NA	0.0 a	0.9 b	0.0 b	1.25 a	--	--	--	--	--
Fusarium spp.	**Tot**	**73.9 a**	**96.3 a**	**100 a**	**99.3 a**	**98.5 a**	**77.2 a**	**94.4 a**	**100 a**	**97.2 a**	**98.8 a**
	Hyp	29.2 b	77.1 c	69.8 d	69.2 c	57.9 d	46.7 b	78.3 b	71.1 c	72.8 c	71.2 c
	Root	69.5 a	87.9 b	90.9 b	85.3 b	85.0 b	72.8 a	82.8 ab	88.3 b	84.4 b	84.4 b
	Peg	NA	73.5 c	92.8 ab	83.6 b	90.8 ab	NA	74.2 bc	93.8 ab	88.3 b	90.0 ab
	Pod	NA	58.5 d	77.5 c	59.6 c	71.1 c	NA	63.6 c	67.0 c	59.2 d	61.9 c

Table 4-5 continued.

		Incidence of isolation (%)									
		1995					1996				
Fungus	Part	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5
Eupenicillium sp.	**Tot**	**1.8**	**3.7**	**9.2**	**14.1**	**26.0**	**7.0**	**9.0**	**14.0**	**10.0**	**300**
		a	**a**	**a**	**a**	**a**	**a**	**a**	**a**	**a**	**a**
	Hyp	1.8	0.0	2.0	5.9	7.3	3.0	1.0	6.0	5.0	2.0
		a	b	bc	b	b	b	a	a	ab	ab
	Root	0.0	1.4	5.5	5.9	11.3	4.0	6.0	11.0	2.0	10.0
		a	ab	abc	b	b	ab	a	a	b	ab
	Peg	NA	3.2	0.5	6.6	9.3	NA	0.0	4.0	2.0	0.0
			a	c	b	b		a	a	b	b
	Pod	NA	0.0	6.5	6.1	12.8	NA	8.0	6.1	4.0	0.0
			b	ab	b	b		a	a	b	b
Lasiodiplodia theobromae	**Tot**	**0.0**	**2.1**	**15.5**	**19.6**	**15.9**	**8.8**	**10.6**	**21.9**	**30.6**	**40.0**
		a	**a**	**a**	**a**	**a**	**a**	**a**	**a**	**a**	**a**
	Hyp	0.0	2.1	5.5	3.8	5.5	5.0	3.8	8.1	12.5	10.0
		a	a	b	c	bc	b	bc	b	b	c
	Root	0.0	0.0	8.0	12.6	9.5	4.4	7.5	10.0	15.0	25.7
		a	b	b	b	b	b	ab	b	b	b
	Peg	NA	0.0	3.4	10.5	7.6	NA	0.0	5.7	15.1	16.4
			b	b	b	bc		c	b	b	bc
	Pod	NA	0.0	4.0	8.4	4.1	NA	0.0	3.9	10.1	11.4
			b	b	bc	c		c	b	b	c
Macrophomina phaseolina	**Tot**	**13.2**	**53.9**	**69.1**	**64.7**	**62.0**	**27.2**	**49.4**	**63.9**	**67.8**	**41.9**
		a	**a**	**a**	**a**	**a**	**a**	**a**	**a**	**a**	**a**
	Hyp	2.0	8.4	6.0	7.0	8.7	2.8	14.4	17.8	12.2	5.6
		b	c	d	d	d	b	bc	c	d	c
	Root	12.2	47.8	47.1	43.1	38.0	23.3	43.9	42.8	38.9	17.5
		a	a	b	b	b	a	a	b	b	b
	Peg	NA	17.9	39.5	40.7	34.9	NA	25.6	39.0	27.9	20.6
			b	b	b	b		b	b	c	b
	Pod	NA	5.7	14.7	25.0	24.7	NA	0.0	21.4	20.7	15.6
			c	c	c	c		c	c	cd	b
Mucor spp.	**Tot**	**1.2**	**8.8**	**39.6**	**46.3**	**33.8**	**0.0**	**6.7**	**40.6**	**50.0**	**51.2**
		a	**a**	**a**	**a**	**a**	**a**	**a**	**a**	**a**	**a**
	Hyp	0.8	3.7	19.6	9.9	11.3	0.0	2.8	8.9	18.3	13.8
		ab	bc	b	d	c	a	b	d	c	c
	Root	0.4	4.4	18.4	22.3	9.6	0.0	2.8	18.3	22.2	13.1
		b	b	bc	bc	c	a	b	bc	c	c
	Peg	NA	2.5	25.4	27.6	21.5	NA	0.9	19.1	31.3	27.5
			bc	b	b	b		b	b	b	b
	Pod	NA	0.9	11.8	9.9	9.3	NA	1.9	9.0	10.0	16.9
			c	c	d	c		b	cd	d	bc
Nectria sp.	**Tot**	**5.8**	**5.7**	**2.5**	**5.0**	**7.3**	**NR**	**NR**	**NR**	**NR**	**NR**
		a	**a**	**a**	**a**	**a**					
	Hyp	1.7	0.0	0.0	0.0	0.0	--	--	--	--	--
		b	b	b	c	b					
	Root	5.0	0.0	0.6	3.1	6.4	--	--	--	--	--
		ab	b	ab	ab	a					
	Peg	NA	0.0	0.0	0.0	0.9	--	--	--	--	--
			b	b	c	b					
	Pod	NA	5.7	2.1	2.0	0.0	--	--	--	--	--
			a	ab	bc	b					

Table 4-5 continued.

		Incidence of isolation (%)									
		1995					1996				
Fungus	Part	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5
Neocosmospora vasinfecta	**Tot**	**7.3**	**42.4**	**51.3**	**54.7**	**56.4**	**22.2**	**51.7**	**57.2**	**71.1**	**56.2**
		a	**a**	**a**	**a**	**a**	**a**	**a**	**a**	**a**	**a**
	Hyp	2.8	7.7	9.8	11.7	5.6	2.8	8.3	5.0	6.1	3.1
		b	d	d	d	d	b	b	d	d	c
	Root	5.7	33.3	39.0	44.5	44.4	16.7	45.6	42.2	52.8	48.1
		a	ab	b	b	b	a	a	b	b	a
	Peg	NA	16.4	18.9	23.9	14.9	NA	10.1	13.0	20.1	13.8
			cd	cd	c	cd		b	cd	c	b
	Pod	NA	26.4	19.7	25.0	19.6	NA	48.5	19.6	28.5	19.4
			bc	c	c	c		a	c	c	b
Nigrospora sp.	**Tot**	**1.2**	**4.0**	**7.4**	**9.7**	**10.8**	**1.9**	**1.2**	**13.8**	**19.4**	**17.8**
		a	**a**	**a**	**a**	**a**	**a**	**a**	**a**	**a**	**a**
	Hyp	0.4	0.7	0.0	0.0	2.0	0.0	0.0	0.6	2.5	2.8
		a	b	b	b	b	a	a	c	d	b
	Root	0.8	1.7	0.7	1.3	2.7	1.9	0.0	3.8	4.4	7.1
		a	ab	b	b	b	a	a	bc	cd	b
	Peg	NA	2.5	6.9	7.2	5.1	NA	2.3	10.8	9.4	10.0
			ab	a	a	b		a**	ab	bc	ab
	Pod	NA	2.8	0.7	2.7	2.1	NA	0.0	2.5	11.3	NA
			ab	b	b	b		a	bc	b	
Paecilomyces sp.	**Tot**	**1.7**	**1.4**	**3.3**	**1.7**	**4.4**	**0.0**	**0.0**	**10.0**	**18.0**	**14.0**
		a	**a**	**a**	**a**	**a**	**a**	**a**	**a**	**a**	**a**
	Hyp	0.0	0.0	0.0		0.0	0.0	0.0	1.0	2.0	1.0
		a	b	a		b	a	a	b	b	b
	Root	1.7	0.0	1.7		0.0	0.0	0.0	3.0	7.0	7.0
		a	b	a		b	a	a	ab	b	ab
	Peg	NA	0.0	1.7		2.2	NA	0.0	5.0	12.0	6.0
			b	a		ab		a	ab	ab	b
	Pod	NA	1.4	0.0		2.2	NA	0.0	5.3	6.0	4.0
			a	a		ab		a	ab	b	b
Penicillium spp.	**Tot**	**53.8**	**87.5**	**96.3**	**93.3**	**97.9**	**71.7**	**85.0**	**95.0**	**92.2**	**93.1**
		a	**B-a**	**a**	**a**	**a**	**a**	**a**	**a**	**A**	**a**
	Hyp	26.3	60.3	73.0	63.9	70.8	43.9	63.9	66.1	62.8	56.9
		c	b	b	bc	cd	c	b	b	b	b
	Root	41.5	66.7	69.0	68.9	88.2	62.8	70.6	63.3	66.1	61.9
		b	b	b	b	b	b	b	bc	b	b
	Peg	NA	40.0	53.6	56.0	67.7	NA	49.4	54.2	56.4	55.0
			c	c	c	d		c	d	bc	b
	Pod	NA	39.6	56.8	71.9	75.8	NA	66.7	55.5	52.5	55.0
			c	c	b	c		b	cd	c	b
Pestalotia sp.	**Tot**	**0.0**	**5.9**	**2.7**	**0.4**	**9.3**	**0.0**	**0.0**	**1.7**	**1.7**	**4.2**
		a	**a**	**a**	**a**	**a**	**a**	**a**	**a**	**a**	**a**
	Hyp	0.0	0.4	0.0	0.0	1.4	0.0	0.0	0.0	0.0	0.0
		a	c	b	a	bc	a	a	b	b	b
	Root	0.0	1.8	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		a	bc	b	a	c	a	a	b	b	b
	Peg	NA	4.1	1.4	0.4	5.7	NA	0.0	0.8	0.8	1.7
			ab	ab	a	ab		a	ab	ab	ab
	Pod	NA	2.4	0.9	0.0	2.8	NA	0.0	1.7	0.8	2.5
			bc	b	a	bc		a	a	ab	ab

Table 4-5 continued.

		Incidence of isolation (%)									
		1995					1996				
Fungus	Part	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5
Phoma sp.	**Tot**	**0.8**	**8.8**	**31.9**	**12.3**	**17.4**	**3.9**	**8.3**	**16.7**	**5.6**	**3.8**
		a	**a**	**a**	**a**	**a**	**a**	**a**	**a**	**a**	**a**
	Hyp	0.4	0.0	2.1	1.3	3.1	0.0	0.6	0.0	0.0	0.6
		a	b	c	c	b	b	b	c	b	bc
	Root	0.4	1.3	6.7	1.7	2.1	3.9	2.2	3.9	1.7	1.2
		a	b	c	c	b	a	b	c	b	bc
	Peg	NA	9.1	22.3	8.5	13.3	NA	9.4	10.1	2.2	1.9
			a**	b	ab	a		a**	b	b	b
	Pod	NA	6.6	7.2	5.5	3.6	NA	1.9	4.0	1.7	0.0
			a	c	bc	b		b	c	b	c
Phomopsis sp.	**Tot**	**0.0**	**0.4**	**7.1**	**14.6**	**26.0**	**0.6**	**6.9**	**23.1**	**31.2**	**32.1**
		a	**a**	**a**	**a**	**a**	**a**	**a**	**a**	**a**	**a**
	Hyp	0.0	0.0	0.0	0.4	0.0	0.6	0.6	2.5	1.9	0.7
		a		b	b	b	a	b	b	b	b
	Root	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.6	0.6	0.0
		a		b	b	b	a	b	b	b	b
	Peg	NA	0.0	7.3	13.3	24.7	NA	10.1	18.3	30.2	32.1
				a[z]	a	a		a[z]	a	a	a
	Pod	NA	0.0	0.0	1.3	1.3	NA	0.0	0.6	1.2	1.4
				b	b	b		b	b	b	b
Pythium spp.	**Tot**	**0.0**	**1.2**	**12.5**	**11.2**	**6.7**	**5.0**	**6.7**	**5.0**	**6.7**	**15.0**
		a	**a**	**a**	**a**	**a**	**a**	**a**	**a**	**a**	**a**
	Hyp	0.0	1.2	3.8	1.2	0.0	3.3	3.3	1.7	1.7	1.7
		a	a	ab	b	a	a	a	a	b	b
	Root	0.0	1.2	2.5	2.5	6.7	3.3	6.7	1.7	1.7	3.3
		a	a	b	b	a	a	a	a	b	b
	Peg	NA	0.0	5.0	2.5	0.0	NA	0.0	1.7	1.7	8.3
			a	ab	b	a		a	a	b	ab
	Pod	NA	0.0	12.5	7.5	0.0	NA	0.0	5.0	5.0	10.0
			a	a	ab	a		a	a	ab	ab
Rhizoctonia solani	**Tot**	**13.2**	**24.9**	**46.3**	**39.3**	**43.6**	**10.6**	**31.1**	**36.1**	**34.4**	**32.5**
		a	**a**	**a**	**a**	**a**	**a**	**a**	**a**	**a**	**a**
	Hyp	10.5	13.8	11.2	7.7	8.2	7.8	18.3	12.8	13.9	7.5
		a	b	c	d	d	ab	b	b	c	c
	Root	5.7	12.4	15.2	7.7	15.0	6.7	15.6	14.4	12.8	8.1
		b	b	c	d	c	b	b	b	c	c
	Peg	NA	11.0	26.8	28.7	31.3	NA	18.0	15.8	24.0	17.5
			b	b	b	b		b	b	b	b
	Pod	NA	2.8	17.2	14.8	16.0	NA	12.1	8.7	8.9	13.1
			c	c	c	c		b	b	c	bc
Rhizopus spp.	**Tot**	**26.2**	**26.0**	**42.8**	**31.8**	**36.7**	**43.9**	**41.7**	**54.4**	**43.9**	**60.0**
		a	**a**	**a**	**a**	**a**	**a**	**a**	**a**	**a**	**a**
	Hyp	17.2	17.7	27.5	21.5	20.0	36.1	31.7	33.9	33.3	48.1
		b	b	b	b	b	b	ab	b	b	b
	Root	20.8	13.0	23.1	12.5	20.9	38.9	32.8	28.3	17.2	36.2
		b	b	b	c	b	ab	ab	b	c	c
	Peg	NA	3.8	12.2	9.1	16.1	NA	22.7	31.1	17.4	26.2
			c	c	cd	b		bc	b	c	cd
	Pod	NA	3.2	8.5	4.4	6.1	NA	18.2	11.6	12.3	22.5
			c	c	d	c		c	c	c	d

Table 4-5 continued.

		Incidence of isolation (%)									
		1995					1996				
Fungus	Part	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5
Sclerotium rolfsii	**Tot**	**1.3**	**2.0**	**1.0**	**0.0**	**7.3**	**0.8**	**2.5**	**2.5**	**5.8**	**4.0**
		a	**a**	**a**	**a**	**a**	**a**	**a**	**a**	**a**	**a**
	Hyp	1.3	0.0	0.0	0.0	0.0	0.8	1.7	0.0	0.8	0.0
		a	a	a	a	b	a	a	b	b	a
	Root	0.0	2.0	0.0	0.0	0.0	0.8	0.0	0.8	0.0	0.0
		a	a	a	a	b	a	a	ab	b	a
	Peg	NA	0.0	0.0	0.0	7.3	NA	2.8	1.7	3.3	4.0
			a	a	a	a		a[z]	ab	ab	a
	Pod	NA	0.0	1.0	0.0	7.3	NA	2.2	0.0	3.4	3.0
			a	a	a	a		a	b	ab	a
Thielavia terricola	Tot	**16.6**	**12.4**	**4.3**	**5.0**	**0.6**	**1.7**	**0.0**	**5.0**	**0.0**	**0.0**
		a	**a**	**a**	**a**	**a**	**a**	**a**	**a**	**a**	**a**
	Hyp	10.9	0.4	0.4	0.4	0	0.0	0.0	0.0	0.0	0.0
		ab	c	b	c	a	a	a	b	a	a
	Root	7.4	4.3	1.9	0.0	0	1.7	0.0	0.0	0.0	0.0
		b	bc	b	c	a	a	a	b	a	a
	Peg	NA	10.6	1.2	1.6	0	NA	0.0	0.0	0.0	0.0
			ab	b	bc	a		a	b	a	a
	Pod	NA	9.4	1.2	3.2	0.6	NA	0.0	5.0	0.0	0.0
			ab	b	ab	a		a	a	a	a
Trichoderma spp.	**Tot**	**36.5**	**68.0**	**83.9**	**72.0**	**82.6**	**30.0**	**56.7**	**69.4**	**73.3**	**79.4**
		a	**a**	**a**	**a**	**a**	**a**	**a**	**a**	**a**	**a**
	Hyp	18.6	51.8	56.8	47.8	62.8	12.8	40.6	46.1	48.3	48.1
		c	b	b	b	b	c	b	b	b	c
	Root	31.7	46.5	59.9	51.2	50.8	23.3	39.4	41.7	48.9	61.2
		b	b	b	b	c	b	b	b	b	b
	Peg	NA	23.0	33.3	30.1	34.9	NA	12.4	30.5	26.2	43.1
			c	c	c	d		c	c	c	c
	Pod	NA	11.3	19.0	21.9	26.8	NA	0.0	22.0	17.9	31.2
			d	d	d	e		d	d	c	d
Zygorhynchus sp.	**Tot**	**3.1**	**5.0**	**9.4**	**5.0**	**7.2**	**1.4**	**2.8**	**5.7**	**10.7**	**11.4**
		a	**a**	**a**	**a**	**a**	**a**	**a**	**a**	**a**	**a**
	Hyp	1.2	0.6	4.2	1.1	3.2	0.0	0.7	2.1	2.8	5.7
		a	c	ab	b	bc	a	a	ab	b	b
	Root	2.5	3.4	5.6	3.9	4.0	1.4	2.1	2.1	7.8	7.1
		a	ab	ab	a	b	a	a	ab	a	b
	Peg	NA	0.7	1.7	0.0	0.8	NA	0.0	0.7	2.1	6.4
			bc	b	b	cd		a	b	b	b
	Pod	NA	1.4	0.6	0.6	0.0	NA	0.0	0.7	0.7	7.1
			bc	b	b	d		a	b	b	b

[v] These variables represent the five windows of crop ages and growth stages during which the peanut plants were sampled in 1995 and 1996.

[w] "Tot" refers to percentage of plants within each window of crop ages from which the fungus was isolated. The value of "Tot" for a single plant was equal to "1" whether a fungus was isolated from only one part of the plant or from all four parts of the plant (hypocotyls, roots, pegs, and pods).

Table 4-5 continued.

[x] Values within a column for each fungus for a specific window of growth stages are not significantly different at the $\alpha = 0.1$ level if the lower case letters beneath the mean percentage for each plant part are the same. Values are not significantly different within rows.

[y] "Hyp" refers to the hypocotyls of the peanut plants.

[z] The mean incidences for the pegs and or pods are rarely greater than the mean incidences for the total plant. This is the result of compensation by the Proc GLM procedure when there is missing data which occurred for samples early in the reproductive stages when pods and pegs may have been present on some, but not all of the plants.

than from the pegs and the pods, while *Phomopsis* sp. was isolated commonly from the pegs. Fungi such as *A. flavus* were generally isolated from roots, hypocotyls, pods, and pegs.

Correspondence Analysis

This statistical technique was used to detect potential relationships between the incidences of selected fungi, the growth stages or crop ages at the time of sampling, the part of the plant from which the fungus was isolated, and the health ratings of the plants from which the fungi were isolated. The units for the points lying along the vertical and horizontal axes are undefined.

The relationships between crop ages and fungal incidence in 1995 are presented in Figure 4-1. Some of the natural groupings of fungi as related to the crop ages of the host are circled. The relationships in increasing crop maturity between the variables T1-T5 and crop age are listed in Table 4-1. The results for the same analysis from 1996 are presented in Figure 4-2. For both years, the variables T1-T5 are positioned in a U-shape. This pattern has been reported as common in the analysis of ecological data (69). The points are ordered so that the age of the host generally increases from right to left along the horizontal axis.

In 1995 and 1996, the incidences of *Chaetomium* sp., *Thielavia terricola*, and *Alternaria* sp. were clustered with peanut plants that were in either vegetative or early reproductive stages of growth (T1, T2) (Figures 4-1 and 4-2). The position of *Rhizopus* spp. and *Cladosporium* sp. shifted between 1995 and 1996, however, in both seasons these fungi were more associated with earlier

Figure 4-1. Simple correspondence analysis from 1995 to establish the relationship between the time of sampling and the incidence of specific fungi isolated from peanut grown in 15 different commercial fields. The variables T1 through T5 represent the five sequential sampling dates during the field season. The fungi are represented as follows *Alternaria* sp. (ALT), *Aspergillus flavus* (AFLA), *Aspergillus niger* (ANI), *Chaetomium* sp. (CHAET), *Choanephora cucurbitarum.* (CHOA), *Cladosporium* sp. (CLAD), *Cunninghamella* sp. (CUN), *Curvularia* spp. (CURV), *Cylindrocladium parasiticum* (CYL), *Fusarium* spp. (FUS), *Lasiodiplodia theobromae* (LAS), *Leptosphaerulina* sp. (LEPTO) *Macrophomina phaseolina* (MAC), *Mucor* spp. (MUC), *Neocosmospora vasinfecta* (NEOC), *Nigrospora* sp. (NIGRO), Penicillium spp. (PEN), Pestalotia sp. (PEST), Phoma sp. (PHOMA), *Phomopsis* sp. (PMPS), *Pythium* spp. (PYTH), *Rhizoctonia solani* (RHZC), *Rhizopus* spp. (RHZP), *Sclerotium rolfsii* (SROL), Thielavia terricola (THIELV), *Trichoderma* spp. (TRIC), and *Zygorhynchus* sp. (ZYGO). Units on the horizontal and vertical axes are not defined when the results are plotted with correspondence analysis.

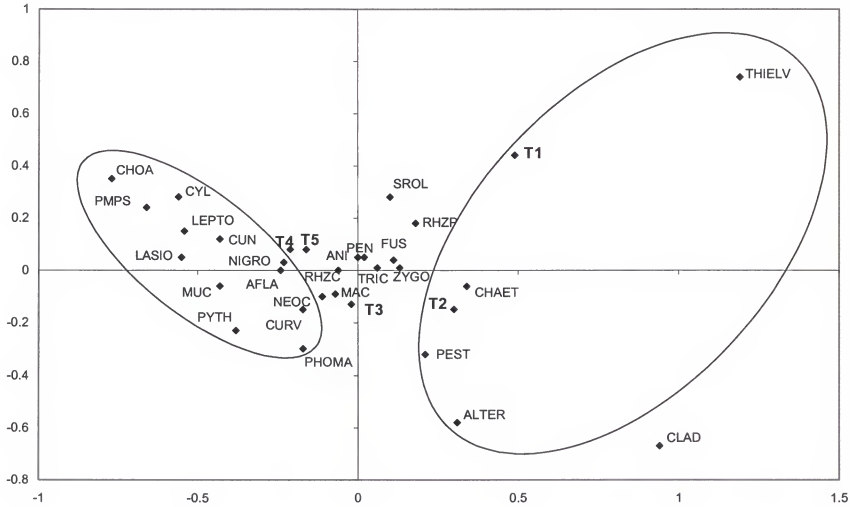
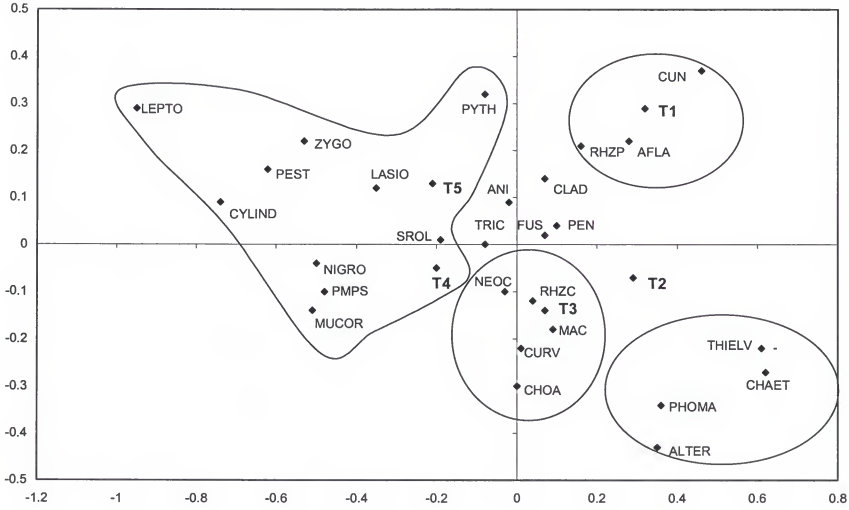

1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-0.5
0
0.5
1
1.5
THIELV
T1
SROL
RHZP
CHOA
CYL
PMPS
LEPTO
CUN
T4
T5
LASIO
NIGRO
ANI
PEN
FUS
RHZC
TRIC
ZYGO
CHAET
T2
MUC
AFLA
NEOC
MAC
T3
PYTH
CURV
PEST
PHOMA
ALTER
CLAD

Figure 4-2. Simple correspondence analysis from 1996 to establish the relationship between the time of sampling and the incidence of specific fungi isolated from peanut grown in nine different commercial fields. The variables **T1** through **T5** represent the five sequential sampling dates during the field season. The fungi are represented as follows *Alternaria* sp. (ALT), *Aspergillus flavus* (AFLA), *Aspergillus niger* (ANI), *Chaetomium* sp. (CHAET), *Choanephora cucurbitarum*. (CHOA), *Cladosporium* sp. (CLAD), *Cunninghamella* sp. (CUN), *Curvularia* spp. (CURV), *Cylindrocladium parasiticum* (CYL), *Fusarium* spp. (FUS), *Lasiodiplodia theobromae* (LAS), *Leptosphaerulina* sp. (LEPTO) *Macrophomina phaseolina* (MAC), *Mucor* spp. (MUC), *Neocosmospora vasinfecta* (NEOC), *Nigrospora* sp. (NIGRO), Penicillium spp. (PEN), Pestalotia sp. (PEST), Phoma sp. (PHOMA), *Phomopsis* sp. (PMPS), *Pythium* spp. (PYTH), *Rhizoctonia solani* (RHZC), *Rhizopus* spp. (RHZP), *Sclerotium rolfsii* (SROL), Thielavia terricola (THIELV), *Trichoderma* spp. (TRIC), and *Zygorhynchus* sp. (ZYGO). Units on the horizontal and vertical axes are not defined when the results are plotted with correspondence analysis.


0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-1.2
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
LEPTO
PYTH
ZYGO
PEST
LASIO
T5
ANI
CLAD
CYLIND
TRIC
FUS
PEN
SROL
NIGRO
T4
NEOC
RHZC
T3
T2
PMPS
MUCOR
MAC
CURV
CHOA
CUN
T1
RHZP
AFLA
THIELV
CHAET
PHOMA
ALTER

sampling dates than with later sampling dates. *Fusarium* spp., *Penicillium* spp., and *Trichoderma* spp. were clustered about the origin in 1995 and 1996 which was interpreted as a general association with the peanut plant during all stages of development. *Neocosmospora vasinfecta*, *R. solani*, *M. phaseolina*, *Curvularia* spp., and *Choanephora cucurbitarum* were clustered with the seed formation stages in 1996 (T3) and separated from *A. niger*, *Penicillium* spp., *Fusarium* spp., and *Trichoderma* spp. This cluster was much less apparent in 1995, but the same groups of fungi were positioned on opposing sides of the vertical axis (Figure 4-1). The opposition of these points was interpreted as a change in association from slightly earlier to slightly later development of the host. In both seasons, the incidences of *Leptosphaerulina* sp., *Phomopsis* sp., *Nigrospora* sp., *C. parasiticum*, *Pythium* spp., and *L. theobromae* were associated with the later growth stages of the peanut crop (T4, T5). The incidences *A. flavus*, *Phoma* sp., and *Cunninghamella* sp. were associated with later growth stages and sampling dates in 1995 than in 1996. The incidence of *S. rolfsii* was associated with a general distribution in 1995 and with later growth stages in 1996.

The relationships between the part of the plant from which a fungus was isolated and fungal incidence are presented in Figures 4-3 and 4-4. The variables P1-P5 are positioned in a U-shaped pattern along the horizontal axis. The hypocotyl region is represented by "P2". The roots are represented by "P3". The pegs are represented by "P4", and the pods are represented by "P5". The total plant is represented by "P1". Fungi clearly associated with a specific part or

Figure 4-3. Simple correspondence analysis from 1995 to establish the relationship between the parts of the plant and the incidence of specific fungi isolated from 15 commercial fields. The variables P1 through P5 represent the five parts of the plant from which fungi were isolated. The total plant is represented by P1, hypocotyls by P2, roots by P3, pegs by P4 and pods by P5. The fungi are represented as follows *Alternaria* sp. (ALT), *Aspergillus flavus* (AFLA), *Aspergillus niger* (ANI), *Chaetomium* sp. (CHAET), *Choanephora cucurbitarum*. (CHOA), *Cladosporium* sp. (CLAD), *Cunninghamella* sp. (CUN), *Curvularia* spp. (CURV), *Cylindrocladium parasiticum* (CYL), *Fusarium* spp. (FUS), *Lasiodiplodia theobromae* (LAS), *Leptosphaerulina* sp. (LEPTO) *Macrophomina phaseolina* (MAC), *Mucor* spp. (MUC), *Neocosmospora vasinfecta* (NEOC), *Nigrospora* sp. (NIGRO), Penicillium spp. (PEN), Pestalotia sp. (PEST), Phoma sp. (PHOMA), *Phomopsis* sp. (PMPS), *Pythium* spp. (PYTH), *Rhizoctonia solani* (RHZC), *Rhizopus* spp. (RHZP), *Sclerotium rolfsii* (SROL), Thielavia terricola (THIELV), *Trichoderma* spp. (TRIC), and *Zygorhynchus* sp. (ZYGO). Units on the horizontal and vertical axes are not defined when the results are plotted with correspondence analysis.

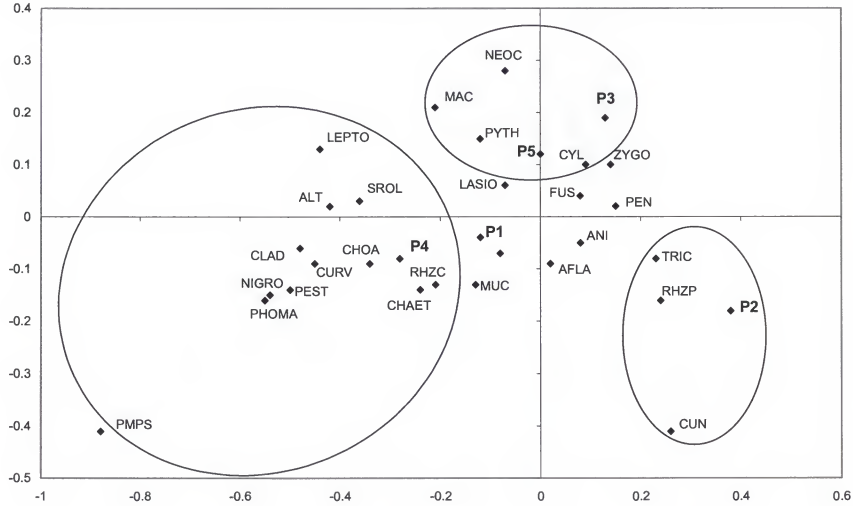
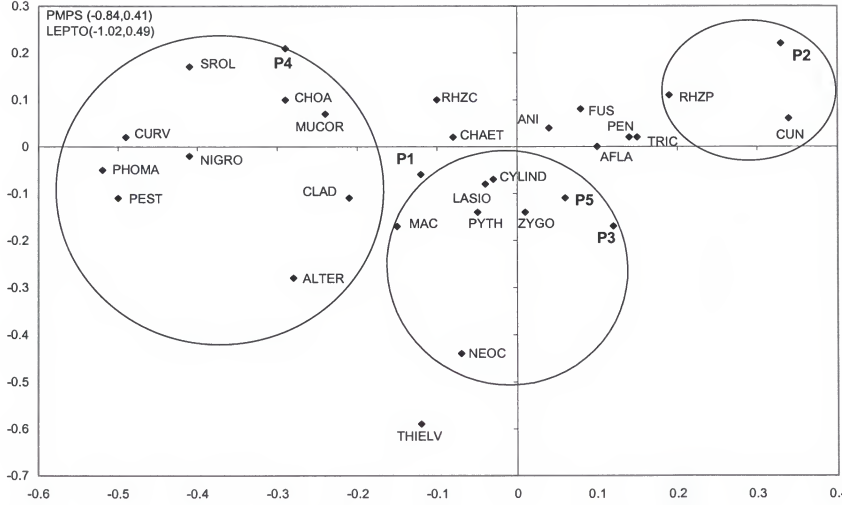

0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
NEOC
MAC
P3
PYTH
P5
CYL
ZYGO
LASIO
FUS
PEN
LEPTO
ALT
SROL
P1
ANI
CLAD
CHOA
P4
TRIC
CURV
RHZC
AFLA
NIGRO
PEST
MUC
RHZP
P2
PHOMA
CHAET
PMPS
CUN

Figure 4-4. Simple correspondence analysis from 1996 to establish the relationship between the parts of the plant and the incidence of specific fungi isolated from nine commercial fields. The variables P1 through P5 represent the five parts of the plant from which fungi were isolated. The total plant is represented by P1, hypocotyls by P2, roots by P3, pegs by P4 and pods by P5. The fungi are represented as follows *Alternaria* sp. (ALT), *Aspergillus flavus* (AFLA), *Aspergillus niger* (ANI), *Chaetomium* sp. (CHAET), *Choanephora cucurbitarum*. (CHOA), *Cladosporium* sp. (CLAD), *Cunninghamella* sp. (CUN), *Curvularia* spp. (CURV), *Cylindrocladium parasiticum* (CYL), *Fusarium* spp. (FUS), *Lasiodiplodia theobromae* (LAS), *Leptosphaerulina* sp. (LEPTO) *Macrophomina phaseolina* (MAC), *Mucor* spp. (MUC), *Neocosmospora vasinfecta* (NEOC), *Nigrospora* sp. (NIGRO), Penicillium spp. (PEN), Pestalotia sp. (PEST), Phoma sp. (PHOMA), *Phomopsis* sp. (PMPS), *Pythium* spp. (PYTH), *Rhizoctonia solani* (RHZC), *Rhizopus* spp. (RHZP), *Sclerotium rolfsii* (SROL), Thielavia terricola (THIELV), *Trichoderma* spp. (TRIC), and *Zygorhynchus* sp. (ZYGO). Units on the horizontal and vertical axes are not defined when the results are plotted with correspondence analysis.


PMPS (-0.84,0.41)
LEPTO(-1.02,0.49)
SROL
P4
CHOA
MUCOR
CURV
NIGRO
PHOMA
PEST
CLAD
ALTER
RHZC
CHAET
P1
CYLIND
LASIO
P5
MAC
PYTH
ZYGO
P3
NEOC
THIELV
ANI
FUS
PEN
TRIC
AFLA
P2
RHZP
CUN
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.6
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4

parts of the plant are circled. During both years, the fungi associated with the pegs were quite different from those associated with hypocotyls while the fungi associated specifically with the roots were similar to those associated with the pods. Fungi that were disproportionately associated with the pegs included *Phomopsis* sp., *Leptosphaerulina* sp., *Alternaria* sp., *S. rolfsii*, *Curvularia* spp., *Nigrospora* sp., *Pestalotia* sp. and *C. cucurbitarum*. Fungi that were disproportionately associated with the roots and the pods included *N. vasinfecta*, *M. phaseolina*, *Pythium* spp., *C. parasiticum*, and perhaps *Zygorhynchus* sp., and *L. theobromae*. *Rhizopus* spp., *Cunninghamella* sp., and perhaps *Trichoderma* spp. were more closely associated with the hypocotyls than were other fungi.

The final results produced with correspondence analysis are presented in Figures 4-5 and 4-6. During both years, the variables related to the disease ratings (R1-R5) given to each peanut plant that was sampled are positioned along the horizontal axis. At the time of assessment, the health ratings were described on a scale of 1-10 (Table 3-6). However, to simplify the results from correspondence analysis, some of the ratings were combined. For this modified scheme, ratings 2 and 3 were combined to produce "R2," ratings 4 and 5 were combined to form "R3," ratings 6, 7, and 8 were combined to form "R4," and ratings 9 and 10 were combined to form "R5." The healthiest rating remained "R1." Those fungi specifically associated with the healthiest plants, such as *T. terricola*, *Cladosporium* spp., *Leptosphaerulina* sp., *Zygorhynchus* sp.,

Figure 4-5. Simple correspondence analysis from 1995 to establish the relationship between the health rating given to each sampled plant and the incidence of specific fungi isolated from 15 commercial fields. The variables R1 through R5 represent the five health ratings given to the plant from which fungi were isolated. A symptomless plant is represented by R1. Plants with discoloration or restricted lesions are represented by R2. The plants with expanding lesions and slight wilt are represented by R3. The plants with more substantial wilt and some necrotic tissue are represented by R4. The plants with severe wilt and necrosis to the point of death are represented by R5. The fungi are represented as follows *Alternaria* sp. (ALT), *Aspergillus flavus* (AFLA), *Aspergillus niger* (ANI), *Chaetomium* sp. (CHAET), *Choanephora cucurbitarum.* (CHOA), *Cladosporium* sp. (CLAD), *Cunninghamella* sp. (CUN), *Curvularia* spp. (CURV), *Cylindrocladium parasiticum* (CYL), *Fusarium* spp. (FUS), *Lasiodiplodia theobromae* (LAS), *Leptosphaerulina* sp. (LEPTO) *Macrophomina phaseolina* (MAC), *Mucor* spp. (MUC), *Neocosmospora vasinfecta* (NEOC), *Nigrospora* sp. (NIGRO), Penicillium spp. (PEN), Pestalotia sp. (PEST), Phoma sp. (PHOMA), *Phomopsis* sp. (PMPS), *Pythium* spp. (PYTH), *Rhizoctonia solani* (RHZC), *Rhizopus* spp. (RHZP), *Sclerotium rolfsii* (SROL), Thielavia terricola (THIELV), *Trichoderma* spp. (TRIC), and *Zygorhynchus* sp. (ZYGO). Units on the horizontal and vertical axes are not defined when the results are plotted with correspondence analysis.

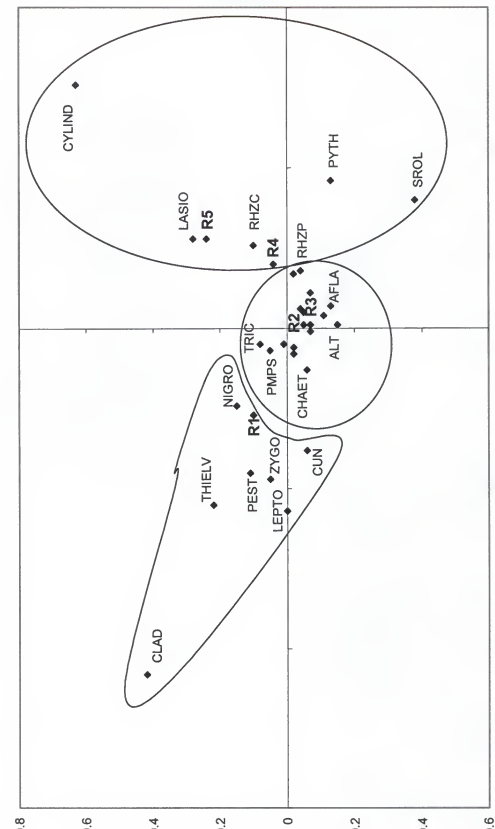
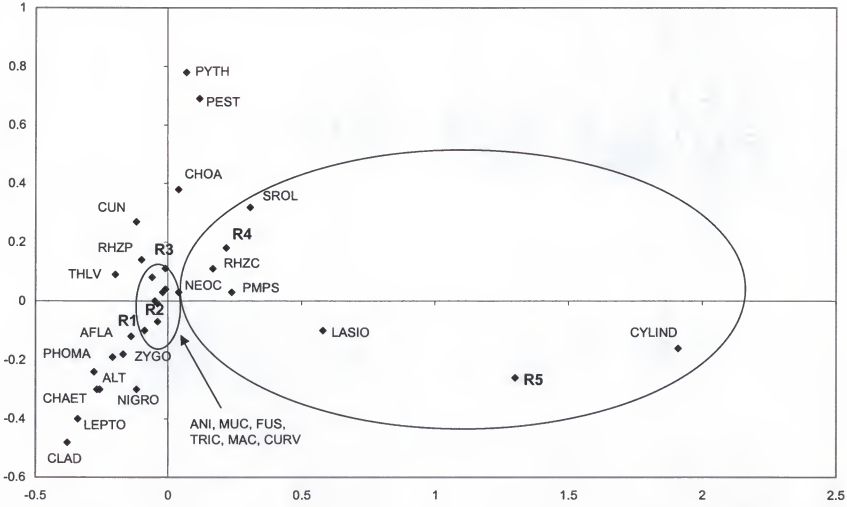

CYLIND
LASIO
R5
RHZC
R4
RHZP
PYTH
SROL
AFLA
R2
R3
TRIC
ALT
PMPS
CHAET
NIGRO
R1
ZYGO
CUN
THIELV
PEST
LEPTO
CLAD
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-1.5
-1
-0.5
0
0.5
1

Figure 4-6. Simple correspondence analysis from 1996 to establish the relationship between the health rating given to each sampled plant and the incidence of specific fungi isolated from nine commercial fields. The variables R1 through R5 represent the five health ratings given to the plant from which fungi were isolated. A symptomless plant is represented by R1. Plants with discoloration or restricted lesions are represented by R2. The plants with expanding lesions and slight wilt are represented by R3. The plants with more substantial wilt and some necrotic tissue are represented by R4. The plants with severe wilt and necrosis to the point of death are represented by R5. The fungi are represented as follows *Alternaria* sp. (ALT), *Aspergillus flavus* (AFLA), *Aspergillus niger* (ANI), *Chaetomium* sp. (CHAET), *Choanephora cucurbitarum.* (CHOA), *Cladosporium* sp. (CLAD), *Cunninghamella* sp. (CUN), *Curvularia* spp. (CURV), *Cylindrocladium parasiticum* (CYL), *Fusarium* spp. (FUS), *Lasiodiplodia theobromae* (LAS), *Leptosphaerulina* sp. (LEPTO) *Macrophomina phaseolina* (MAC), *Mucor* spp. (MUC), *Neocosmospora vasinfecta* (NEOC), *Nigrospora* sp. (NIGRO), Penicillium spp. (PEN), Pestalotia sp. (PEST), Phoma sp. (PHOMA), *Phomopsis* sp. (PMPS), *Pythium* spp. (PYTH), *Rhizoctonia solani* (RHZC), *Rhizopus* spp. (RHZP), *Sclerotium rolfsii* (SROL), Thielavia terricola (THIELV), *Trichoderma* spp. (TRIC), and *Zygorhynchus* sp. (ZYGO). Units on the horizontal and vertical axes are not defined when the results are plotted with correspondence analysis.


1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.5
0
0.5
1
1.5
2
2.5
PYTH
PEST
CHOA
SROL
CUN
R4
RHZP
R3
RHZC
THLV
NEOC
PMPS
R1
R2
AFLA
LASIO
CYLIND
PHOMA
ZYGO
R5
ALT
CHAET
NIGRO
LEPTO
ANI, MUC, FUS,
TRIC, MAC, CURV
CLAD

Cunninghamella sp., and *Nigrospora* sp., were different from those associated with the more diseased plants, such as *S. rolfsii*, *C. parasiticum*, *R. solani*, *Phomopsis* sp., and *L. theobromae*. The position of *Pythium* spp. varied between 1995 and 1996.

Discussion

Interactions of Soilborne Fungi and Parasitic Nematodes

Interactions among different soilborne fungi associated with the peanut plant are potentially both beneficial and harmful in the production of a healthy crop and satisfactory yields. For example, the fungus *T. harzianum* is parasitic to *S. rolfsii*, though efforts to use it in the control of southern stem blight in the field have been unsuccessful (53, 182). Pod rot, a potentially serious disease that affects peanut, was linked to a complex of fungal pathogens and plant parasitic nematodes that included *Pythium myriotylum*, *Fusarium solani*, *R. solani*, and *Meloidogyne arenaria* (55, 73). However, colonization of peanut pods by *R. solani* has also been shown to reduce the development of pod rot in pods that were later exposed to *P. myriotylum* (73). In this same study, high populations of *M. phaseolina* were found to nullify the beneficial effect of *R. solani*. The plant parasitic nematodes *Meloidogyne hapla, M. arenaria*, and *Macroposthonia ornata* can increase the severity of Cylindrocladium black rot (60, 64). Damage by *M. arenaria* was not found to affect the infection of the peanut pods by *A. flavus* (17).

In the current study, significant correlations were found between the incidences of specific fungi and also between specific fungi and parasitic

nematodes. The incidences of *A. niger* and *L. theobromae, Fusarium* spp. and *S. rolfsii, Pythium* spp. and *N. vasinfecta*, *Fusarium* spp. and *M. phaseolina*, and *Phomopsis* spp., *L. theobromae*, and *C. parasiticum* were positively and significantly correlated with each other during the combined seasons of 1995 and 1996 (Table 4-2). Due to the ubiquitous nature of *Fusarium* spp. its relationships with *M. phaseolina* and *S. rolfsii* are likely unimportant. Significant positive correlation between *N. vasinfecta* and *Pythium* spp. would be important to growers if infection by the common, but weak, pathogen *N. vasinfecta* predisposed the host to further infection by *Pythium* spp. or if pod rot was more severe when both fungi were present. *Neocosmospora vasinfecta* may play some role in pod rot of peanut as this fungus was observed to sporulate on rotted pods on several occasions during the course of this study (unpublished data).

Significant positive correlations between *L. theobromae* and *A. niger*, *Phomopsis* sp., and *C. parasiticum* are potentially more important to the grower. *Lasiodiplodia theobromae* is recognized as a wound pathogen, though plants with Diplodia collar rot may not appear to be wounded by cultivation or damaged by other microorganisms, insects, or nematodes (139). Predisposition of the peanut plant to infection by *L. theobromae* by any of these three fungi may help to explain part of the disease cycle for Diplodia collar rot. In the pathogenicity studies that were reported in Chapter 3, *L. theobromae* caused severe disease in peanut plants over a range of growth stages; yet Diplodia collar rot is of modest importance in Florida. *Cylindrocladium parasiticum* and *L. theobromae*

may form a complex of pathogens, where *C. parasiticum* produces wounds through which *L. theobromae* can infect the plant. This complex could be capable of causing severe rot of roots, pods, and pegs.

Negative correlations between the incidences of *L. theobromae* and *C. parasiticum* and *Trichoderma* spp. may be the result of some parasitic activity by *Trichoderma* spp. on these two pathogens. This explanation is partly supported by results from the competitive interaction study presented in Table 3-14. A biological explanation for the negative correlation between the incidences of *R. solani* and *S. rolfsii* is lacking, though there could be some form of competition between the two fungi.

The Interpretation of the relationships between the incidences of soilborne fungi and levels of the parasitic nematodes *Meloidogyne* spp. and *Pratylenchus* spp. was difficult. In 1995 and 1996, the incidences of *A. niger* and *Rhizopus* spp. were positively correlated with the population of *Pratylenchus* spp. sampled during early reproductive growth of the host (Table 4-3). During both years, the incidences of *Chaetomium* sp., *L. theobromae*, and *N. vasinfecta* were negatively correlated with the population of *Meloidogyne* spp. extracted from root tissue. The incidence of *C. parasiticum* was not significantly correlated with populations of either nematode, though the incidence of *R. solani* was negatively correlated with the incidence of the root-knot nematode during pegging.

Pratylenchus spp. (lesion nematode) can cause substantial tissue destruction to the roots, pods, and pegs of the peanut plant, and this damaged tissue may be colonized by other microorganisms (26). Such damage to the

tissue is a possible cause for the correlation between *A. niger*, *Rhizopus* spp., and the lesion nematode. Population levels of the root-knot nematode may have been too low to determine similar relationships that might be expected based upon earlier research (59, 64, 73).

Negative correlations between the incidences of *Chaetomium* sp., *L. theobromae*, and *N. vasinfecta* and root-knot nematodes may be the result of lower populations of the root-knot nematodes in fields with higher incidence of these fungi rather than any biological interactions between the nematodes and the fungi. For example, cotton is a host of *L. theobromae* but is not a host for *M. arenaria*. The use of cotton in rotation with peanut results in significant reductions in root knot nematodes (105). However, high incidences of *L. theobromae* were observed in this study in areas of Florida where cotton was frequently grown in rotation with peanut.

Soil Fertility, pH, and the Incidence of Soilborne Fungi

Management of soil fertility is an important factor in the growth of healthy peanut plants and production of a profitable crop (49). The effects of the nutrients and the pH of the soil are not only related to the physiological development of the plant, but can be factors in the severity of soilborne diseases. For example, a critical level of calcium must be available to the developing pods within the pegging zone (54, 56, 57), and insufficient calcium is a factor in the development of pod rot (55). However, potassium and magnesium ions in the pegging zone can compete with calcium for uptake by the pod and thus interfere with normal development (49, 55, 79). High levels of

phosphorus have been found to lead to increased galling and egg production by the root-knot nematode, *Meloidogyne arenaria* (41). Finally, low pH values are associated with soils that are suppressive to *R. solani* (43). The growth of *T. harzianum*, a fungus pathogenic to *R. solani*, was enhanced by the low pH of the soil (43).

In this study, the pH of the soil sampled from the commercial fields during 1995 and 1996 was consistently positively correlated with the incidence of *Pythium* spp. Infection of plant tissue by *Pythium* spp. is influenced by the pH of the soil (20). Levels of calcium in the commercial fields soon after planting were negatively correlated with the incidences of *Chaetomium* sp. and *C. parasiticum* and with the incidence of *R. solani* at the time of pegging during both seasons. The incidence of *Rhizopus* spp. was positively correlated with the concentration of calcium in the soil early in the season. The incidences of a number of fungi, that included *L. theobromae*, *N. vasinfecta*, *Phomopsis* sp., and *A. niger,* were positively correlated with the concentrations of magnesium and potassium in the soil. The incidences of *C. parasiticum*, *M. phaseolina*, and *Chaetomium* sp. were positively correlated with the concentration of potassium. Neither *Pythium* spp. nor *R. solani*, two fungi commonly associated with peanut pod rot were included in this group. However, the incidence of *Pythium* spp. was positively correlated in both 1995 and 1996 with the concentration of phosphorus in the soil. Cause-and-effect cannot be decided based upon correlation analysis; however, the biological basis for relationships in this study between incidences of soilborne fungi and fertility can be supported with earlier research (43, 49, 54, 55, 56, 57).

Cultural Practices, Yield, and the Incidence of Soilborne Fungi

Rotation with crops that are non-hosts for soilborne pathogens is a common and important tactic in the management of disease. Therefore, it was expected that the incidences of the important soilborne pathogens of peanut that were isolated in this study, that included *R. solani*, *S. rolfsii*, *C. parasiticum*, *A. niger*, *Pythium* spp., and *L. theobromae*, would decrease as the rotations used by the growers improved. Although the incidences of *R. solani, A. flavus*, and *Pythium* spp. were negatively correlated with improved crop rotation during a single season, only the incidences of *A. niger, Rhizopus* spp., and *L. theobromae* were consistently correlated with rotation during both 1995 and 1996. The severity of Aspergillus crown rot, caused by *A. niger,* has been associated with poor crop rotation (123). The low incidences of pathogens such as *S. rolfsii* and *Pythium* spp. may explain, in part, why a relationship with rotation was not observed for some fungi.

The incidence of *L. theobromae* was positively correlated with improved crop rotation, which could be important in the future based on this pathogen's close association with *C. parasiticum* (Table 4-2) and its pathogenicity (Chapter 3). In some areas of Florida, especially in the Panhandle (including Jackson and Santa Rosa Counties), cotton is frequently grown in rotation with peanut. Cotton is considered to be a good rotation crop for peanut because it is a non-host or a poorer host for pathogens of peanut, such as *C. parasiticum*. However, cotton is a host for *L. theobromae* and may help to increase inoculum levels of this fungus

in the soil. Baird et al. (13) found that the isolation frequency of *L. theobromae* from peanut pods was significantly greater in peanut grown in rotation with cotton than in peanut grown in rotation with either bahiagrass or peanut.

To reduce the severity of seedling blights, peanut seeds should be planted when the temperature of the soil is high enough to support rapid germination and growth of the seedling (104, 114). In this study, the incidence of some soilborne fungi actually increased in those fields with later planting dates (Table 4-3). For *Pythium* spp., this may be a coincidence since it was found in only few fields and two of these fields (Fields 109 and 204) were normally planted later in the season after the harvest of potatoes. However, infection by *Pythium* spp. are influenced by the temperature of the soil and the optimum temperature for the growth of *P. myriotylum* is reported as 35° C (20) Outbreaks of Aspergillus crown rot have been associated with high temperatures early in the season (121). Later planting dates are likely be associated with higher temperatures during seedling growth and thus a greater predisposition to the effects of *A. niger*.

As with crop rotation, it was expected that increased yields and quality would be associated with reduced incidences of important soilborne pathogens. However, only the increased incidence of *R. solani* was consistently associated with a reduction in yield, and only the increased incidence of *Rhizopus* spp. was associated with decreased quality during both 1995 and 1996. The incidence of *Pythium* spp. was negatively correlated with yield in 1996 and the incidences of *A. niger , A. flavus*, and *Pythium* spp. were associated with a reduction in quality

during a single year. The incidence of *C. parasiticum* was associated with a reduction in quality in those fields from which it was isolated.

The lack of negative correlation between yield, grade, and the incidence of fungal pathogens may be explained in at least two different ways. First, the populations of the pathogenic fungi may have been low enough that they did not cause any obvious reduction in yield or quality. Secondly, many factors contribute to the final yield and quality of that yield, including the presence of pathogens. Potential losses due to disease may have been compensated for by these other factors. Whereas the populations of soilborne pathogens may have caused severe reductions in yield and quality in some fields, overall their impact was difficult to measure using correlation analysis.

The Community of Soilborne Fungi in the Peanut Plant

An ecological community is defined as "any assemblage of populations of living organisms in a prescribed area or habit" (107). If this "area or habit" is defined as the portion of the peanut plant that develops beneath the surface of the soil, then the soilborne fungi that colonize the peanut plant may belong to a single fungal community. A community can be further defined as "collections of virtually the same groups of species in space and time" (107). This definition does not require any specific interactions between the members of the community other than that they occur together. In the simplest interpretation of the results from this study, at least 48 genera and an unknown number of species form the community of soilborne fungi associated with peanut in Florida.

An important objective of this study was to determine if the incidences of the soilborne fungi that were isolated from the roots, hypocotyls, pegs, and pods of the peanut plants changed over a growing season. For some of the most important fungi that infected peanut, the mean square values for the main effects of crop age at the time of sampling and for the plant part examined were highly significant (Table 4-4). Incidences of these fungi during the season were not static and changed over the season. Also, the incidences of these fungi varied between the different parts of the plant. The eight fungi described in Table 4-4 were selected based upon their importance as fungal pathogens. Their results were representative of most of the other fungi that were isolated.

Changes in the incidences of fungi over time are well documented in the literature. For example, *Trichoderma konoigii* and *Penicillium* spp. were the initial colonizers of the roots of bean (*Phaseolus vulgaris*) cultivar Prince, while *Fusarium* spp. and *Gliocladium roseum* were more frequently isolated from the surfaces of older roots (65). *Chaetomium* sp., *Fusarium* spp., *Penicillium* spp., *Trichoderma* spp., and *Gliocladium roseum* colonized the roots of young soybean plants, though the incidences of *Chaetomium* sp. and *Penicillium* spp. declined rapidly (126). Garren (75) found that the incidences of soilborne fungi isolated from both sound and rotted peanut pods changed during the season. For example *Chaetomium* sp. was much more common earlier in the season while the incidence of *Trichoderma* spp. was greater near the end of the season. In another study, the incidence of *R. solani* was greatest on seedlings and was found to predispose the plants to later colonization by fungi such as *Fusarium*

equisetii and *Cochliobolus sativus* (88). *Pythium* sp. was isolated from seedlings of barley, flax, and wheat, though its incidence declined markedly as the plants developed (136). The incidence of *Pythium* sp. on the roots of cotton was also found to be dependent on changes in the season, primarily environmental, though the colonization of the roots by *R. solani, Trichoderma* spp., and *Gliocladium* spp. was fairly constant over the season (98).

From the results presented in Table 4-5 and in Figures 4-1 and 4-2, not only do the incidences of most fungi change significantly over time, but fungi can be grouped based upon similarities in these changes. For example, in both Figure 4-1 and 4-2, the incidences of *Leptosphaerulina* sp., *Phomopsis* sp., *Nigrospora* sp., *Lasiodiplodia theobromae, Pythium* spp., *Mucor* spp., and *Cylindrocladium parasiticum* were associated with the plants at the later reproductive growth stages. Fungi such as *Thielavia terricola*, *Chaetomium* sp., and *Alternaria* sp. were consistently associated by correspondence analyses with earlier growth stages. These general trends were also supported by comparing the mean values for the total incidence of each of these fungi (Table 4-5).

Similar kinds of groups can be detected when the relationships are analyzed between the part of the plant from which isolations were made and the incidences of the fungi (Table 4-5 and Figures 4-3 and 4-4). For example, the incidences of *Phoma* sp., *Phomopsis* sp., *Nigrospora* sp., *Alternaria* sp., and *S. rolfsii* were closely associated with the pegs while the incidences of *Rhizopus*

spp. and *Cunninghamella* sp. were associated with the hypocotyls. Again, these general trends were evident in the results from analysis of variance in Table 4-5.

Change in communities over time is an important concept in the study of ecology. A sere has been defined as the "whole sequence of communities that replace one another in a given area" (131). The changing communities over time are referred to as seral stages, developmental stages, or pioneer stages (131). The development of seral stages on new peanut tissue would be described as "primary succession" because the colonization occurred on a substrate that was not previously colonized by fungi (131).

Other researchers have developed an alternative concept to describe the changes in composition of a natural grouping of fungi over time. Forbes and Davet (69) based their description of changes in the composition of fungi from the roots of soybean on the patterns of isolation of fungi from soil along strong "gradients of higher plant continua" as described by Bisset and Parkinson (22). For these researchers, fungal associations, both temporal and spatial, were better described as "progressively changing groups instead of discrete communities" (22). In their study of the associations of soilborne fungi with the roots of soybean, Forbes and Davet (69) noted changes in the incidences of fungi within a season, but they felt that changes were not distinct enough to warrant a differentiation of communities of fungi.

In plant pathology, some researchers (99) have carefully differentiated seral communities as defined by Odum (131) while choosing not to "interpret minor changes in the density of different fungi as evidence of new and distinct

communities." These researchers would probably accept both concepts, seral communities and progressively changing groups, as valid descriptions of the dynamics within their fungal system. In 1968, Jackson (99) identified communities of soilborne fungi associated with developing peanut pods. A single community was associated with the geocarposhere, two seral communities were associated with the seeds, and a single community was associated with peanut shells. His decision to separate the seral communities of the seeds was based upon the disappearance or replacement of certain groups of fungi by other fungi (99). The causes for the apparent succession of the fungal communities on the peanut seeds were unknown, but Jackson (99) noted that the change occurred after the seeds had matured, and that maturity led to changes in the chemical and physical characteristics of peanut seed.

Five seral communities of fungi were associated with distinct growth stages of corn, *Zea mays*, in Florida (185). Again, minor fluctuations in the density of taxa were ignored in defining communities. Successional communities were described as groups of fungi that invaded, reached their maximal frequency, and declined in frequency at approximately the same time. Although the fungi were not placed into specific communities, the changes in incidences of soilborne fungi associated with the roots of soybean over a season were similar to that described for corn (126). The incidences of some fungi peaked and then declined later in the season while the incidences of other fungi remained constant over the season.

In contrast, in their preliminary study on the fungal communities on the roots and shoot bases of winter barley and winter wheat, Dawson and Bateman (62) simply described changes in composition of the fungi between samples taken in January and samples taken in June. They did not attempt to differentiate the groups of fungi from each season into separate communities.

The community of soilborne fungi that was associated with peanut in Florida progressed through three major stages of development that were associated with growth stages of the host (Table 4-1 and Figures 4-1 to 4-4). The diversity of the community increased with each stage of development; however, most of the fungi continued to belong to a single dynamic community over time. Fungi that belonged to this community could be grouped with the stage or stages of community development in which they reached some relative importance. The groups of fungi that existed at each stage of development did not belong to distinct communities because there were very few examples of replacement of any taxa of fungi by other fungi. Once important taxa were established in the community, their incidences tended to remain relatively constant. The increased diversity of fungi was evidence of the dynamic nature of this community.

Only late in the season did a second distinct community develop and it was associated with the pegs. This peg community of soilborne fungi coexisted with the larger, general community of soilborne fungi and was not completely exclusive in composition. The different mycoflora associated with the pegs may result because these structures originated above the soil line and grew into the

soil. While above the soil or at the soil surface, they may be colonized by fungi less likely to infect beneath the soil.

The earliest and dominant "foundational" stage in the development of the general community occurred soon after the peanut seeds germinated. This foundational stage contained soilborne fungi that colonized the young seedlings, maintained high incidences throughout most of the season, commonly infected the roots, hypocotyls, pegs, and pods, and were found abundantly throughout the production regions of Florida. Fungi commonly isolated during the foundational stage included *A. niger*, *Penicillium* spp., *Fusarium* spp., and *Trichoderma* spp.

A "secondary" stage of development occurred during later vegetative growth and early reproductive growth stages. Fungi that emerged during the secondary stage were also fairly common over the production regions of the state. However, their incidences tended not to reach the same magnitude as those found in the foundation stage and they were less conspicuous during the seedling stage, though they may have been present. These fungi were less likely to be associated with the hypocotyl and more likely to be associated with the roots and the pegs, or the roots and the pods. Members of this stage included *R. solani*, *N. vasinfecta*, *Curvularia* spp., and *M. phaseolina*.

The "tertiary" stage of community development coincided with the development of the pods, seed formation, the closure of the foliar canopy, and physiological changes that may have occurred in the peanut plant as maturity approaches. The unifying features of the fungi that emerged during the tertiary

stage were their association primarily with the later sampling dates characterized by the presence of pegs and maturing pods, and their isolation from the roots and pegs or roots and pods. This stage includes *C. parasiticum, Pythium* spp., *L. theobromae*, and *Zygorhynchus* sp.

The "peg" community of fungi emerged at the same time as the tertiary stage of development. The peg community was differentiated from the larger general community by its very close association with the peg and with much lower association with any other part of the plant. The fungus that was most prominent in this community was *Phomopsis* sp. which was readily isolated from the pegs, but was much less frequently isolated from the pods, roots, or hypocotyls. Other members of the peg community included *Nigrospora* sp., *Mucor* spp., *Leptosphaerulina* sp., *Choanephora cucurbitarum*, and *S. rolfsii*. Although their incidence was more transitory than those listed above, *Phoma* sp. and *Alternaria* sp. also probably belonged to the peg community.

Another group of fungi that belonged to the general community included those fungi that reached their relative prominence during the first half of the growing season, but their incidence declined later in the season. These fungi also tended to have greater associations with the pegs and pods. Members of this "transitory" group included *T. terricola* and *Chaetomium* sp. Other fungi, such as *Rhizopus* spp., *A. flavus,* and *Cunninghamella sp.,* could not be placed in a single stage, but were rather general members of the general community. The incidence of these fungi remained fairly small, yet consistent, throughout the season and they were commonly isolated from the hypocotyl, unlike many of the

other soilborne fungi. A final "ephemeral" group included those fungi that were isolated with very low frequencies throughout the season. Members of this ephemeral group included *Cladosporium* sp., *Nectria* sp., *Colletotrichum* sp., *Gloeosporium* sp., *Gliocladium* sp., *Bipolaris* sp., and *Pestalotia* sp. The apparent ephemeral nature of these fungi may have been from their low incidences that made reliable isolation difficult.

Connell and Slatyer (48) proposed three mechanisms to explain successions of ecological communities. The first mechanism was explained by the "tolerance" model, where organisms with different strategies to exploit resources, such as the r-selected and K-selected species discussed earlier, become established on a substrate at different times. Examples of fungal pathogens that would be considered relatively r-selected include *Botrytis cinerea* and species of *Pythium, Phytophthora*, and *Helminthosporium*. Plant pathogens that would be considered relatively K-selected include *Armillaria mellea*, *R. solani*, and *Gymnosporangium juniperi-virginianae* (120). A second mechanism was the facilitation model. In the facilitation model, organisms in the earlier communities predispose the host or environment in some way so that it is habitable for other organisms. An example of this occurs when secondary invaders colonize plant tissue killed by a pathogen. The final mechanism proposed by Connell and Slatyer (48) was the inhibition model. In the inhibition model, species resist replacement by competitors, but random events over time allow colonization by other species.

Although *R. solani* has been described as a K-selected species, nearly all of the fungi isolated from peanut in this study, and especially the deuteromycetes, would be classified as r-selected due to their rapid rates of asexual reproduction. The incidences of most of the important fungi that reached some maximum earlier in the season did not decline with the appearance of other fungi, thus, it does not appear as though changes in the community of soilborne fungi associated with peanut followed the tolerance model. The inhibition model is also unlikely as similar trends in the development of the fungal community were seen between 1995 and 1996. The use of the facilitation model would be appropriate here, and the fungi that were the earliest colonizers of the seedlings predisposed the plants to colonization by other fungi. However, this concept is often associated with an early infection by a pathogen and the subsequent colonization of wounded tissue by saprophytes. In peanut, the most important pathogens were associated with the end of the season.

The mechanism for the temporal changes in the community of soilborne fungi associated with peanut in Florida was probably similar to that observed by Young and Kucharek (185) who reported that five seral communities of fungi were associated with distinct growth stages of corn, *Zea mays*. Changes in the structures of the fungal communities in corn, soilborne community, and the development of the peg community were largely due to changes that occurred in the host during its growth.

Soilborne Fungi and the Health of the Peanut Plant

The relationships between the incidences of soilborne fungi on subterranean parts of peanut and the health ratings given to each plant sampled in 1995 and 1996 are presented in Figures 4-5 and 4-6. Those fungi that were associated with the most severely diseased plants (R4 and R5) were clearly separated from the rest of the community. *Cylindrocladium parasiticum*, *L. theobromae*, *R. solani*, *Pythium* spp., and *S. rolfsii* were disproportionately associated with diseased plants. *Neocosmospora vasinfecta* and *Phomopsis* sp., might also have had some slight association with diseased plants. However, the relationship between *Phomopsis* sp., and rating may be the result of its appearance at the same time as the most important pathogens. The associations of *Leptosphaerulina* sp., *Cladosporium* sp., *T. terricola*, *Pestalotia* sp., and *Cunninghamella* sp. with the healthiest plants was probably the result of their prominence earlier in the season prior to the development of severe diseases caused by soilborne pathogens. The incidences of most fungi were positioned near the origin, which is interpreted as colonization by these fungi did not affect the health of the plant.

Conclusions

The incidences of soilborne fungi associated with peanut production in Florida can be affected by the incidences of other fungi, crop production practices, such as rotation, and soil fertility factors. The correlation between the incidences of *L. theobromae* and *C. parasiticum* and the circumstantial evidence for the increase in *L. theobromae* when peanut was gown in rotation with cotton

are potentially important to the growers of Florida. Also, the positive correlation between the concentrations of magnesium and potassium and the incidences of a number of soilborne fungi is also of interest.

The soilborne fungi that colonize peanut in Florida belong to a dynamic general community that progresses through stages of development associated with changes in the peanut plant and to a community associated with the pegs of the plant. The stages in the development of the general community can be described as foundational, secondary, and tertiary. The diversity of the general community increased at each stage of development and also contains fungi, such as *Rhizopus* spp. and *A. flavus* that were not associated with a single stage. A number of fungi that belong to the peg community were associated with foliar diseases of peanut. The behavior of a fungus in a single field was also influenced by a number of factors in addition to the host that would have some impact on its colonization of the plant.

Most of the soilborne fungi that were isolated from the peanut were not associated with symptoms of disease and most of those that were associated, were already recognized as pathogens. The importance of *N. vasinfecta* to the overall health of the peanut plant in Florida may deserve further study.

CHAPTER 5
SOILBORNE FUNGI AND THREE CULTIVARS OF PEANUT

Introduction

In a survey of commercial fields and research plots planted with peanut in 1995 and 1996, forty-eight genera of soilborne fungi were isolated from the parts of the plant that grow below the surface of the soil. The incidences of many of these fungi changed in predictable patterns over the growing season, and two distinct communities could be described based upon these patterns and preferential colonization of different parts of the plant.

Because a large portion of the surveys from 1995 and 1996 were conducted in commercial fields, there was no experimental control over the cultivars of peanut from which the fungi were isolated. The most common cultivars were Florunner and GK-7, though other cultivars, including Sunrunner, Andru, SunOleic 95R, NCV 11, and Georgia Runner, were also planted. Management of the crop during the season included decisions about planting dates, fungicide programs, and harvest dates and was the responsibility of the grower. Therefore, it was not possible to determine the effects that different cultivars of peanut might have on the composition of the natural groupings or the incidences of fungi during the season.

The use of specific cultivars to manage soilborne diseases is an important consideration for the grower. However, it is of limited benefit in peanut

production because cultivars with complete resistance to major soilborne diseases are not yet available (164). Research has been conducted to understand the partial resistance that some cultivars have to soilborne diseases. Branch and Csinos (29) found that among 16 cultivars of peanut, valencia market types were significantly more susceptible to southern stem blight, caused by *Sclerotium rolfsii*, than were Spanish, runner, or Virginia types. Those cultivars with the fewest disease foci did not necessarily have the largest yields. Smith et al. (163) evaluated eight breeding lines, three parents, and the cultivar Florunner for resistance to southern stem blight and pod rot caused by *Pythium myriotylum*. The incidences of southern stem blight and rotted pods were greater in Florunner than in TxAG-3. Incidence of southern stem blight was greater in Florunner than in breeding lines for which TxAG-3 was a parent.

Another important soilborne disease of peanut in some areas of Florida is Cylindrocladium black rot caused by the fungus *Cylindrocladium parasiticum*. Delays in the onset of disease epidemics have been found to be one characteristic of cultivars that have some resistance to this disease (58). Cortex and stele tissue dissected from the taproots of susceptible cultivars have been shown to have higher infection levels of *C. parasiticum* than cultivars with partial resistance (175). Also, germination of microsclerotia of *C. parasiticum* was found to be higher in the rhizosphere of a susceptible cultivar of peanut than it was in a cultivar with partial resistance to Cylindrocladium black rot (110). Finally, isolates of *C. parasiticum* from cultivars with partial resistance to

Cylindrocladium black rot tend to be more virulent than those from susceptible hosts (24).

The objective of this study was to evaluate the influence of three cultivars of peanut, Florunner, Florida MDR 98, and Georgia Green, on the incidences of 14 soilborne fungi on roots, pods, pegs, and hypocotyls throughout two seasons. The results could be used to determine if the composition of the natural groupings of soilborne fungi identified from general surveys was affected by the cultivar of peanut. Also, the results could be used to determine if the parts of the plant colonized by these fungi or periods of infection differed among cultivars.

The three cultivars were selected based upon there importance to the growers in Florida. Currently, Florunner is rarely planted commercially in the southeastern United States because it is very susceptible to Tomato spotted wilt virus, but it was a dominant cultivar for many years. The cultivar Florida MDR 98 was recently released from the peanut breeding program at the University of Florida by Dr. D. W. Gorbet. It may have partial resistance to southern stem blight (183). Georgia Green has become one of the most important cultivars planted in the southeastern United States today.

The fourteen fungi that were evaluated during this study included the important pathogens *Sclerotium rolfsii, C. parasiticum, Lasiodiplodia theobromae, Aspergillus niger, Aspergillus flavus, Rhizoctonia solani,* and *Pythium* spp. (9, 20, 31, 55, 71, 96, 122, 123, 143, 172). Also included were the weaker pathogens *Neocosmospora vasinfecta*, *Fusarium* spp., *Rhizopus* spp., and *Macrophomina phaseolina*. *Trichoderma* spp. and *Zygorhynchus* sp. were

included, as they have been reported to be parasitic to some soilborne fungal pathogens (35, 36, 53, 159, 182). *Phomopsis* sp. was included in the study because of its close association with the pegs of the peanut plant. Because it was isolated almost exclusively from pegs in the general surveys, the incidence of *Phomopsis* sp. could be used to check the accuracy of correspondence analysis to represent true associations among soilborne fungi. *Fusarium* spp., which was commonly isolated throughout the season and from all parts of the plant, was also used as a similar check.

Materials and Methods

This study was conducted during 1998 and 1999 in Block 57 at the North Florida Research and Education Center in Quincy, Florida. Block 57 had been planted in peanut each summer since at least 1990 and the soil had been periodically infested with sclerotia of *S. rolfsii* for other studies (Shokes, personal communication). Prior to 1998, the presence of *C. parasiticum* was unknown in this field. The field normally remained fallow between peanut seasons. Pivot irrigation was available for the site.

Seed

In 1998, seed for Florunner was obtained from the Fugate seed producers in Williston, Florida. In 1999, the Fugate family no longer produced seed for this cultivar, and the seed was obtained from the Florida Seed Foundation in Marianna, Florida. Seed for Florida MDR 98 was obtained from the foundation both in 1998 and in 1999. Seed for Georgia Green was obtained from the Fugate seed producers in 1998 and 1999.

Planting

The soil in block 57 was turned and then disked several times in the early spring prior to planting. The tests were planted on 8 May 1998 and 14 May 1999 in a spit-plot experimental design. The test in 1999 had to be replanted on 10 June 1999 because of poor germination by Georgia Green. The rows were planted from north to south on 91.4-cm centers. Block 57 slopes gently from west to east and the eastern edge can become flooded after heavy rains. This portion of the field was planted with additional border rows of Georgia Green to facilitate weed control. Border rows were not evaluated in the test. Each whole plot was 12.2 meters long by four rows wide. Each replication of treatments ran from north to south. The test consisted of four replications of each whole plot treatment (cultivar). Alleys that were 4.6 meters wide separated the whole plots within each replication. Ten subplots were randomized within each whole plot. Subplots were 1.2 meters long and four rows wide.

The peanut seeds were planted approximately 3.8 cm deep; the soil had adequate moisture for rapid germination. Approximately 20 seeds were planted per meter of row. In 1998, the insecticide phorate (Thimet®) was applied at planting (7.9 kg ha^{-1}) to reduce the severity of tomato spotted wilt virus by control of thrips. Phorate was not applied in 1999. The fields were planted with a New Holland 4630 tractor that pulled a dual Cole planter. The plants in the block were irrigated throughout the season with a pivot system when rainfall was insufficient. Clorothalonil (tetrachloroisophthalonitrile, Bravo Ultrex® 82.5 WDG) was applied at a rate of 1.6 kg ha^{-1} (1.4 pounds per acre) approximately every 10 to 14 days.

Applications in 1998 began 4 weeks after planting but did not begin until 6 weeks after planting in 1999. Foliar diseases were not a problem in 1998. Severe defoliation of Florunner and Georgia Green occurred in 1999 as inoculum of *Cercosporidium arachidicola* from neighboring peanut plots arrived prior to the first application of fungicide. The cultivar Florida MDR 98 was largely unaffected by foliar disease in either year. In 1998, gypsum was broadcast over the plots at a rate of 568 kg ha^{-1} (500 pounds per acre) as the peanut pods began to form. No additional gypsum was applied in 1999. Post-emergent applications of the herbicides paraquat (Starfire®) and bentazone (Basagran®) were made to the plots in both years. Imazameth (Cadre®) and sethoxydim (Poast®) were applied later in the season as needed to maintain control of weeds.

Sampling

Soil samples were collected from block soon after planting during both seasons to determine the presence of microsclerotia of *C. parasiticum* and sclerotia of *S. rolfsii*. In 1999, the samples were only assessed for *C. parasiticum* because results from 1998 on the sclerotia of *S. rolfsii* did not correlate with natural inoculum levels in the field. Soil samples were collected on 1 June 1998. The test was divided into a western portion (replications I and II) and an eastern portion (replications III and IV). Each of these portions was subdivided into 15 blocks that were eight rows wide and 2.44 m long. Within each of these smaller blocks, two soil samples were collected per row to a depth of 12.7 cm (5 inches) for a total of 16 samples per sub-block, or 240 samples for each half of the test. The 16 soil samples from within each sub-block were

combined and placed in a cooler. In 1999, 10 soil samples were collected from the four rows of each whole plot and bulked together. These were also collected to a depth of 12.7 cm.

Protocol to Process Soil Samples for Propagules of *Cylindrocladium parasiticum*

This procedure was modified from the techniques of Tylka and Hunter (178) and Krigsvold and Griffin (108) to estimate the number of microsclerotia of *C. parasiticum* contained in a sample of soil. The method was as follows. 1) The soil was air-dried. 2) Fifty grams of field soil were weighed into a plastic dish. 3) The soil was washed with tap water through a stack of three sieves (coarse, 149-μm mesh, and 38-μm mesh). 4) Any organic matter, such as roots and stems, were caught in the coarse sieve and this matter was removed and placed in a blender at high speed for 30 seconds. The blended material was then washed again through the sieves. Blending of organic matter was not repeated in 1999 because of the the limited organic matter present in each sample. 5) The portions from the 149-μm mesh and 38-μm mesh sieves were washed into separate plastic containers with a 0.25% sodium hypochlorite solution. The samples remained in the hypochlorite solution for 25 seconds. 6) The samples were then poured back through the sieves and rinsed with tap water. The soil that remained in each of the two sieves was rinsed into two different 250 mL beakers with sterilized water and brought to a final volume of 75 mL. The mixture of soil and water was stirred vigorously on a magnetic stir plate and 1-mL aliquants were removed and placed on glucose-lima bean-rose bengal agar (GRBLA) and incubated in darkness at 25°C until colonies could be identified

beginning 5 days later. The number of propagules of *C. parasiticum* per gram of soil was calculated by multiplying the number of colonies on each plate (the number present in a 1-mL aliquant) by the factor of 75 mL/50 grams of soil. Two plates were prepared from the soil collected on the 149-μm mesh sieve, and two plates were prepared from the soil collected on the 38-μm mesh sieve. The two values obtained from each sieve were averaged and then the two means were summed to give a final value for the total number of propagules from a single sample of soil.

Protocol to Estimate the Number of Sclerotia of *Sclerotium rolfsii* in 50 Grams of Soil

This procedure was modified from Rodrigues-Kabana et al. (147). After the soil samples were air-dried, 50 grams were removed from each sample and spread evenly into a large petri plate and misted to soil capacity with a solution of 0.1% (v/v) of methanol and water. Two plates were prepared for each sample. Each petri plate was sealed with parafilm and stored at room temperature. The presence of *S. rolfsii* was detected by the growth of characteristic mycelium across the soil surface. This procedure was not continued in 1999 because the low incidence of *S. rolfsii* detected on the plates was not proportional to the incidence of disease observed in the field.

Sampling of Plants During the Season

Plants were destructively sampled from each whole plot beginning 2 weeks after planting. Sampling continued on a biweekly basis throughout the remainder of the season so that plants were collected on eight occasions. Ten

subplots were randomized within each of the whole plots and initially designated as subplots 1-10. On each of the eight collection dates, 10 plants were destructively sampled from within the appropriate subplots. Five plants were removed from each of the two western rows. Plants were selected based upon their position in the row (approximately 20 cm apart) and not upon the presence or absence of symptoms of disease. Plants were removed with a shovel to collect a sizeable portion of the hypocotyl, root system, pods and pegs. Excess foliage was removed in the field and the 10 plants from each plot were placed in labeled plastic bags. The plastic bags were placed in an ice cooler and then transported to the laboratory.

The severity of soilborne disease for each whole plot on each collection date was estimated by measuring the length of wilted row in the undisturbed two eastern rows. Wilt that could be attributed to tomato spotted wilt virus was not included in this evaluation. The incidence of tomato spotted wilt virus was low in 1998 for all varieties, though it was an important consideration in 1999 for Florunner and Georgia Green. In instances where the stand of peanuts in a particular whole plot was incomplete due to poor germination, disease severity was normalized for a complete plot. A final yield was measured from these two unsampled rows in each whole plot. The peanut trials were dug on 7 October 1998 and 27 October 1999. In both years, harvest was delayed because of wet weather. In 1998, the peanuts were dug and combined on the same day. In 1999, the peanuts were not combined until 29 October. The bags of harvested

peanuts were placed in dryers and the pods were dried to a moisture content of 10%.

Sample Processing

Five of the plants that were sampled from each subplot were processed as described in the Materials and Methods section of Chapter 3. In 1998 and 1999, lesions from the lower limbs or crown were analyzed with the hypocotyl tissue to isolate soilborne pathogens.

Assessment of the Microclimate

The development of the foliar canopy was monitored by measurement of the height and width of rows in each whole plot on the sampling dates. The microclimate (soil temperature, air temperature, and relative humidity) within the developing foliar canopy and within the pegging zone was monitored in 1999 with Cricket-H temperature and relative humidity recorders, and Cricket-T temperature recorders (Avatel, Inc., Ft. Bragg, CA). One Cricket-H and one Cricket-T were used for each cultivar for a total of six in all. The data loggers were placed in the field on the first sampling date and remained in the field until the final sampling date. The data logger that collected soil temperatures was placed in the pegging zone five cm below the soil surface in close proximity to a young plant. The data logger used to measure relative humidity and air temperature was enclosed in a thermal shield to prevent exposure to direct sunlight, and then placed within the row of peanuts. The detector was eventually completely enclosed by the foliar canopy. The development of the canopy around the thermal shields is pictured in Figure 5-4. The objective of the

detectors was to associate changing patterns of isolation of important fungi such as *C. parasiticum* and *S. rolfsii* with changes in temperature and relative humidity within the soil and canopy.

Data Analysis

Yields from both years were analyzed by analysis of variance and the means were separated by the procedure for least significant differences. The area under the disease progress curve (AUDPC) was calculated for each whole plot and analyzed by analysis of variance and the least significant differences. The apparent infection rate, "r", was calculated for each whole plot using the monomolecular model for monocyclic pathosystems (179). The mean apparent infection rates for each cultivar were analyzed by analysis of variance. Incidences of the 14 fungi were evaluated over the season by correspondence analysis to determine if the incidence of the fungi was influenced by the cultivar of peanut. Correspondence analysis was also used to evaluate differences in the incidence of the fungi based upon isolation from different parts of the plant and on the health rating of each sampled plant. To reduce the number of ratings against which the incidence of the fungi was compared, the 10 health ratings were combined as follows. A health rating of "1" remained unchanged. A health rating of "2" represented a combination of the original ratings of 2 and 3. A health rating of "3" represented a combination of the original ratings of 4, 5, and 6. A health rating of "4" represented a combination of the original health ratings of 7 and 8. Finally, a heath rating of "5" represented a combination of the original ratings of 9 and 10. The author encircled groups of closely related points on the

plots generated with correspondence analysis to facilitate interpretation by the reader.

Results

Despite a delay in planting in 1999 because of poor seed germination, the age of the plants at the times of sampling was similar in 1998 and 1999 (Table 5-1). Growth stages at the times of sampling were nearly identical as well. Harvest in 1998 was delayed by wet weather and schedule conflicts. Projected harvest dates are 135 days after planting for both Georgia Green and Florunner and 150 days after planting for Florida MDR 98. Harvest in 1998 was late for Florunner and Georgia Green, and in 1999 harvest was early for Florida MDR 98.

The severity of soilborne disease, which was described using two variables, the area under the disease progress curve (AUDPC) and the apparent infection rate (r), was greater and yield was significantly lower in Florunner than in Florida MDR 98 (Table 5-2). In 1998, disease severity was significantly lower in Georgia Green than in Florunner, though the yields were not significantly different. Disease severity was measured as the length of wilted row at each sampling date in the two unsampled rows of each whole plot. The length of wilted row in plots where the stand was less than 100% was proportionally adjusted to provide an estimate of wilt in a complete plot. The apparent infection rate was not calculated in 1999 because of the small amount of soilborne disease that was present. In 1998, typical disease progress curves

Table 5-1. Sampling information from a cultivar trial at the North Florida Research and Education Center, at Quincy.

		1998			1999		
Event	Cultivar	Date	Days after planting	Median growth stage[z]	Date	Days after planting	Median growth stage[z]
Planting		8 May			10 Jun		
Sample 1		21 May	13		23 Jun	13	
	Florunner			V3			V2
	Florida MDR 98			V2			V1-V2
	Ga Green			V2-V3			V2
Sample 2		8 Jun	31		7 Jul	27	
	Florunner			V5			V4-V5
	Florida MDR 98			V3-V5			V4
	Ga Green			V5			V5
Sample 3		16 Jun	39		20 Jul	40	
	Florunner			R1			R1
	Florida MDR 98			R1			R1
	Ga Green			R1			R2
Sample 4		29 Jun	52		2 Aug	53	
	Florunner			R2			R2-R3
	Florida MDR 98			R2			R2
	Ga Green			R2			R3
Sample 5		13 Jul	66		17 Aug	68	
	Florunner			R4			R4
	Florida MDR 98			R4-R5			R4
	Ga Green			R4			R5
Sample 6		27 Jul	80		30 Aug	81	
	Florunner			R6			R5
	Florida MDR 98			R5-R6			R6
	Ga Green			R6			R6
Sample 7		10 Aug	94		13 Sept	95	
	Florunner			R7			R7
	Florida MDR 98			R7			R6
	Ga Green			R7			R7
Sample 8		21 Aug	105		28 Sept	110	
	Florunner			R7			R8
	Florida MDR 98			R7			R7
	Ga Green			R7			R8
Harvest		7 Oct	152		27 Oct	139	

[z] A summary of the growth stages of the peanut plant is presented in Table 3-5; briefly, V1-V6 = vegetative stages in increasing maturity and R = reproductive stages with R1 = beginning bloom, R2 = beginning peg, R3 = beginning pod formation, R4 = full pod formation, R5 = beginning seed formation, R6 = the full seed stage of development, R7 = beginning maturity, and R8 = harvest maturity of the pods.

Table 5-2. Yield and disease severity among three cultivars of peanut grown at the North Florida Research and Education Center, Quincy during 1998 and 1999.

	Yield (kg per whole plot)		AUDPC[v]		Apparent Infection rate[w] (r)		R^2 value for 1998
Cultivar	1998[x]	1999[y]	1998[x]	1999[y]	1998[x]	1999	"r"
Florunner	2.6 B	3.4 B	731 A	61 A*	0.14 A	NE[z]	0.93
Florida MDR 98	5.6 A	5.0 A	140 B	19 B*	0.02 C	NE	0.90
Georgia Green	3.1 B	2.9 B	416 B	49 AB*	0.06 B	NE	0.92

[v] "Area under the disease progress curve" was used as a measure of disease severity.
[w] The apparent infection rate was determined with the monomolecular model, [ln(1/(1-y))], to transform disease severity measure in the length of wilted row at each sampling date.
[x] The values from 1998 followed by different letters are significantly different at the $\alpha = 0.05$ level.
[y] The values from 1999 followed by different letters are significantly different at the $\alpha = 0.1$ level.
[z] NE: the apparent infection rate was not evaluated for 1999 due to the low severity of soilborne disease that occurred.

were best described as bicyclic. Very little disease severity was noted before the middle of the season, when many wilted plants began to appear. The apparent infection rate was calculated for this later period by transforming the disease severity using the monomolecular model, [ln (1/(1-y))], and then the slope of the best-fit line was determined between transformed points. The R^2 value, to represent the goodness of fit of the monomolecular model to this data from 1998, is presented in the final column of this table.

The microsclerotia of *C. parasiticum* were scattered throughout Block 57 in both 1998 and 1999, though microsclerotia were not recovered from a number of plots. In 1998, the average number of microsclerotia in the plots ranged from 0 to 4.5 per gram of soil. Few sclerotia of *S. rolfsii* were observed in 1998, though southern stem blight was common during the second half of the season.

The relationships between the development of the foliar canopies and the age of the peanut plants are presented in Figure 5-1. Data prior to 66 days after planting were not collected in 1998. Rapid growth of the canopy began approximately 40 days after planting. In 1998 the canopy closed by 80 days after planting for Florunner and by 94 days after planting for FL MDR 98 and Georgia Green. In 1999, perhaps due to the late planting date, the canopies of the three cultivars did not completely close during the season. However, the canopy for Florunner was nearly completely closed by 81 days after planting.

The temperature within the canopy and in the pegging zone began to drop 55 to 60 days after planting, and the relative humidity within the canopy generally increased during this period (Figures 5-2, 5-3). The development of the canopy

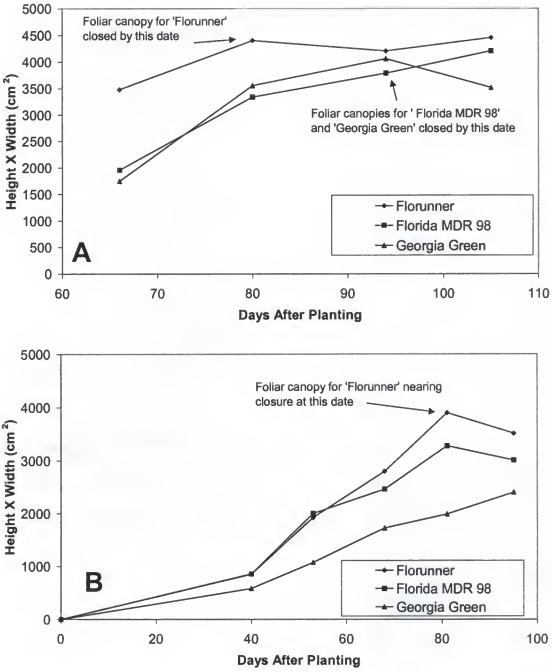

Foliar canopy for 'Florunner' closed by this date
Foliar canopies for ' Florida MDR 98' and 'Georgia Green' closed by this date
Florunner
Florida MDR 98
Georgia Green
A
Height X Width (cm 2)
Days After Planting
Foliar canopy for 'Florunner' nearing closure at this date
B

Figure 5-1. Development of the foliar canopy among three cultivars of peanut at the North Florida Research and Education Center in 1998 (A) and 1999 (B). The development of the canopy was measured as the product of the height of the canopy and the width of the canopy measured at a single representative point in each subplot sampled on a given date. The points on the graph represent the mean value for each cultivar at each date.

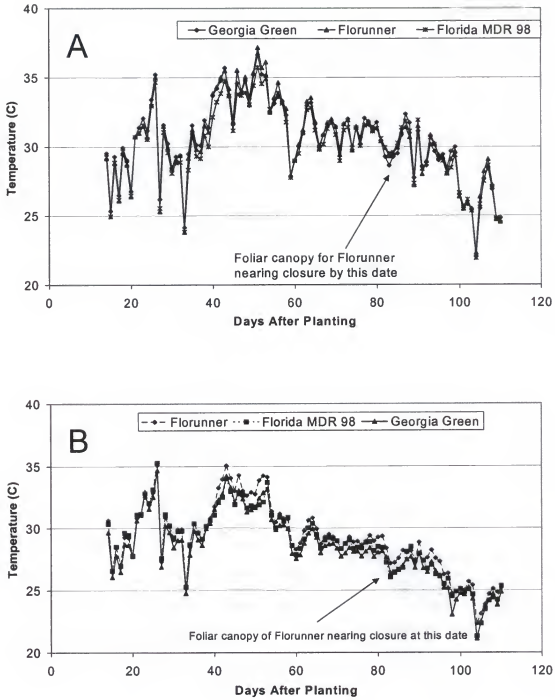


Figure 5-2. Changes in temperature of the canopy (A) and soil (B) associated with three cultivars of peanut at the North Florida Research and Education Center, Quincy during 1999. Each point represents the average temperature from 9:00 AM until 6:00 PM measured hourly.

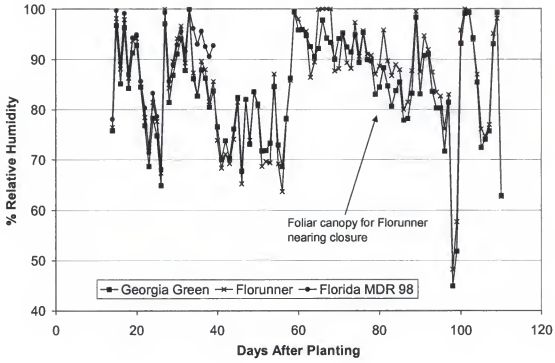


Figure 5-3. The changes in % relative humidity within monitoring stations placed in the developing canopies of three cultivars of peanut at the North Florida Research and Education Center, Quincy. Each point on this graph represents the value for the % relative humidity averaged over measurements taken each hour between 9:00 AM and 6:00 PM.

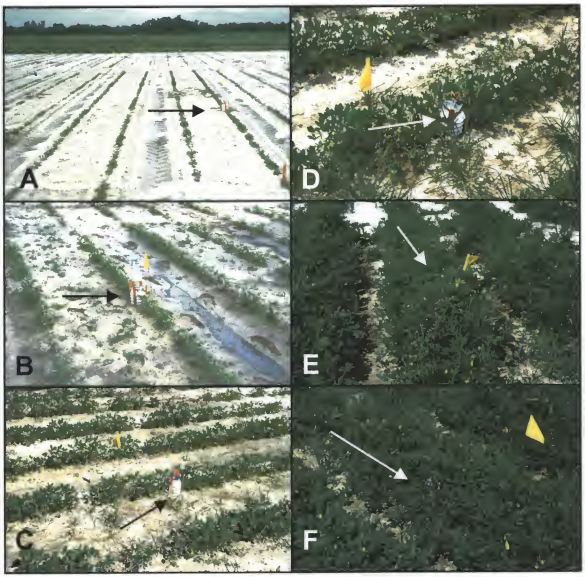


Figure 5-4. Development of foliar canopy at the North Florida Research and Education Center, Quincy, during June-September, 1999. Soil temperature recorders were buried at flags. Canopy temperature and % relative humidity recorders were protected by shields marked by arrows. A. 13 days after planting. B. 27 days after planting. C. 40 days after planting. D. 53 days after planting. E. 81 days after planting. F. 95 days after planting.

around a protective shield is shown in Figure 5-4. The recorder to collect soil temperature was buried near the flag in each picture. The recorder to collect the temperature and relative humidity from within the developing canopy was contained in a thermal shield to protect it from direct solar radiation. Therefore, the data were related to conditions in the canopy, but were also influenced by the protective shield. For instance, any condensation on the probe that measured relative humidity may have taken longer to evaporate in the morning than if the recorder had not been shielded. However, if the data recorder had not been shielded, it would have been excessively heated by direct solar radiation. Each point on the graphs in these figures represent the mean value for data collected hourly between 9:00 AM and 6:00 PM which was the warmest part of the day.

Based upon the results from correspondence analysis, the incidences of the soilborne fungi from this study formed two or three major groups in association with the time of sampling and the growth stage of the host (Figures 5-5, 5-6). The incidences of *C. parasiticum* (3A, B, C) from all three cultivars, *L. theobromae* in Florida MDR 98 and Georgia Green (5B, 5C), *Phomopsis* sp. (8A, B, C), and *S. rolfsii* from Florunner (12A) were associated with the oldest plants in both years. In both figures, the sampling dates (represented by T1 through T8) were generally defined along the horizontal axis from right to left. Sampling dates were directly related to the age and growth stage of the crop (Table 5-1). Points positioned near the origin represented fungi with incidences that were more evenly distributed over the entire season and least affected by sampling

Figure 5-5. Simple correspondence analysis from 1998 to establish the relationship between the time of sampling and the incidence of specific fungi isolated from three different cultivars of peanut. The variables T1 through T8 represented the eight sequential sampling dates during the field season. The letters A, B, and C represent the cultivar of peanut from which the isolations were made. The cultivar 'Florunner' is represented by A, the cultivar 'Florida MDR 98' by B, and the cultivar 'Georgia Green' by C. The fungi are represented as follows: *Aspergillus flavus* (1), *Aspergillus niger* (2), *Cylindrocladium parasiticum* (3), *Fusarium* spp. (4), *Lasiodiplodia theobromae* (5), *Macrophomina phaseolina* (6), *Neocosmospora vasinfecta* (7), *Phomopsis* sp. (8), *Pythium* spp. (9), *Rhizoctonia solani* (10), *Rhizopus* spp. (11), *Sclerotium rolfsii* (12), *Trichoderma* spp. (13), and *Zygorhynchus* sp. (14). Units on the horizontal and vertical axes were not defined when the results from correspondence analysis were plotted.

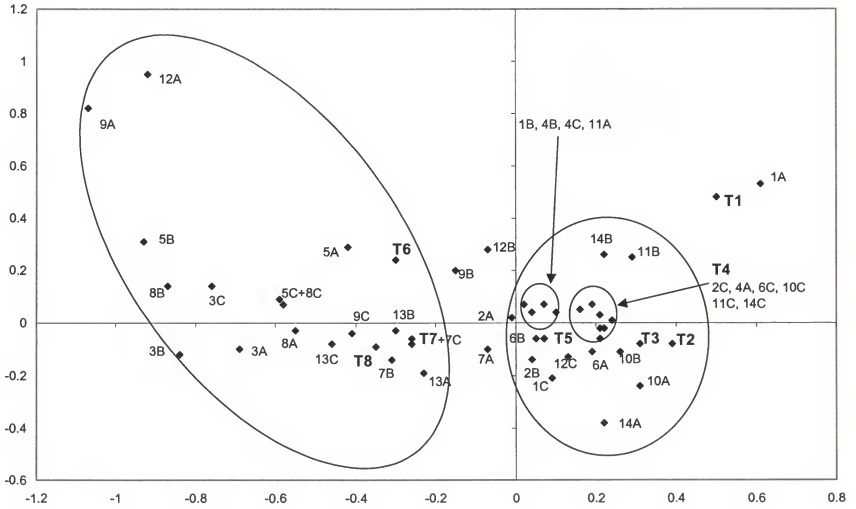
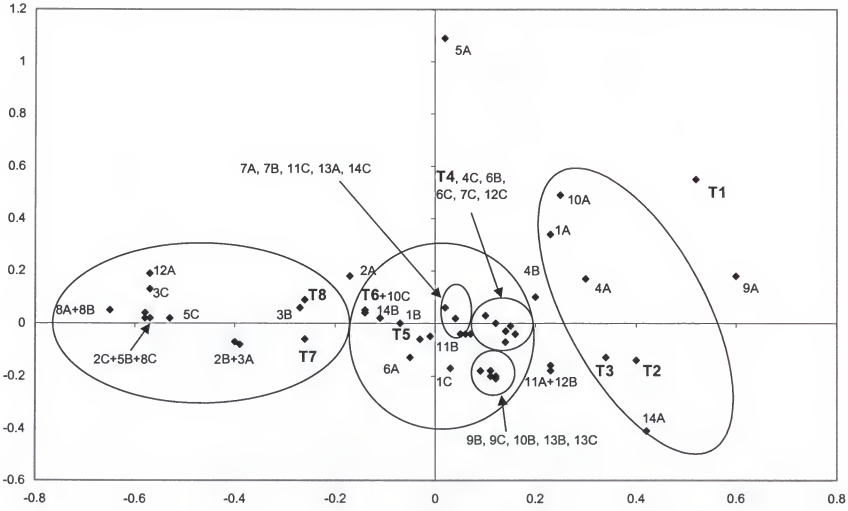

1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-1.2
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
12A
9A
5B
8B
3C
5C+8C
3B
3A
8A
13C
9C
13B
T8
7B
T7+7C
13A
5A
T6
9B
12B
2A
7A
1B, 4B, 4C, 11A
6B
T5
2B
1C
12C
6A
14B
11B
T4
2C, 4A, 6C, 10C
11C, 14C
T3
T2
10B
10A
14A
1A
T1

Figure 5-6. Simple correspondence analysis from 1999 to establish the relationship between the time of sampling and the incidence of specific fungi isolated from three different cultivars of peanut. The variables T1 through T8 represent the eight sequential sampling dates during the field season. The letters A, B, and C represent the cultivar of peanut from which the isolations were made. The cultivar 'Florunner' is represented by A, the cultivar 'Florida MDR 98' by B, and the cultivar 'Georgia Green' by C. The fungi are represented as follows: *Aspergillus flavus* (1), *Aspergillus niger* (2), *Cylindrocladium parasiticum* (3), *Fusarium* spp. (4), *Lasiodiplodia theobromae* (5), *Macrophomina phaseolina* (6), *Neocosmospora vasinfecta* (7), *Phomopsis* sp. (8), *Pythium* spp. (9), *Rhizoctonia solani* (10), *Rhizopus* spp. (11), *Sclerotium rolfsii* (12), *Trichoderma* spp. (13), and *Zygorhynchus* sp. (14). Units on the horizontal and vertical axes were not defined when the results from correspondence analysis were plotted.


1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
5A
7A, 7B, 11C, 13A, 14C
T4, 4C, 6B,
6C, 7C, 12C
10A
T1
1A
12A
2A
4B
4A
9A
3C
T8
T6+10C
8A+8B
5C
3B
14B
1B
T5
11B
2C+5B+8C
2B+3A
T7
6A
T3
T2
1C
11A+12B
14A
9B, 9C, 10B, 13B, 13C

date. Fungi that were positioned near the origin included *R. solani* (10A, B, C), *M. phaseolina* (6A, B, C), and *Rhizopus* spp. (11A, B, C). Points that were positioned away from the origin and in association with one or more sampling dates represented fungi whose incidences were disproportionately associated with those periods of time and the growth stages that they represented. The incidences of *A. flavus* (1A, B, C), *Fusarium* spp. (4A, B, C), and *Zygorhynchus* sp. (14A, B, C) were either associated with young plants (T1, T2) or were associated with plants in all growth stages as they were positioned near the origin.

There were several differences in the plot from 1998 and the plot from 1999. In 1998, the incidences of *Trichoderma* spp. (13A, B, C), *N. vasinfecta* (7A, B, C), and *Pythium* spp. (9A, B, C) were associated with more mature growth stages (T6, T7, T8), while in 1999, the incidence of these fungi were positioned closer to the origin. In 1998, the incidence of *A. niger* (2A, B, C) was positioned close to the origin, but in 1999, *A. niger* was associated with later growth stages.

Based upon the results from correspondence analysis, the incidences of some fungi were disproportionately associated with a part or parts of the peanut plant (Figures 5-7 and 5-8). The variable P1 represented the entire underground portion of the plant, P2 represented the hypocotyls and crown regions, P3 represented the root system, P4 represented the pegs, and P5 represented the pods. In both 1998 and 1999, the total underground portion, P1, was positioned very close to the origin, while the four individual parts radiated away from it.

Figure 5-7. Simple correspondence analysis from 1998 to establish the relationship between the parts of the plant and the incidence of specific fungi isolated from three different cultivars of peanut. The variables P1 through P5 represent the five parts of the plant from which fungi were isolated. The total plant is represented by P1, hypocotyls by P2, roots by P3, pegs by P4. and the pods by P5. The letters A, B, and C represent the cultivar of peanut from which the isolations were made. The cultivar 'Florunner' is represented by A, the cultivar 'Florida MDR 98' by B, and the cultivar 'Georgia Green' by C. The fungi are represented as follows: *Aspergillus flavus* (1), *Aspergillus niger* (2), *Cylindrocladium parasiticum* (3), *Fusarium* spp. (4), *Lasiodiplodia theobromae* (5), *Macrophomina phaseolina* (6), *Neocosmospora vasinfecta* (7), *Phomopsis* sp. (8), *Pythium* spp. (9), *Rhizoctonia solani* (10), *Rhizopus* spp. (11), *Sclerotium rolfsii* (12), *Trichoderma* spp. (13), and *Zygorhynchus* sp. (14). Units on the horizontal and vertical axes were not defined when the results from correspondence analysis were plotted.

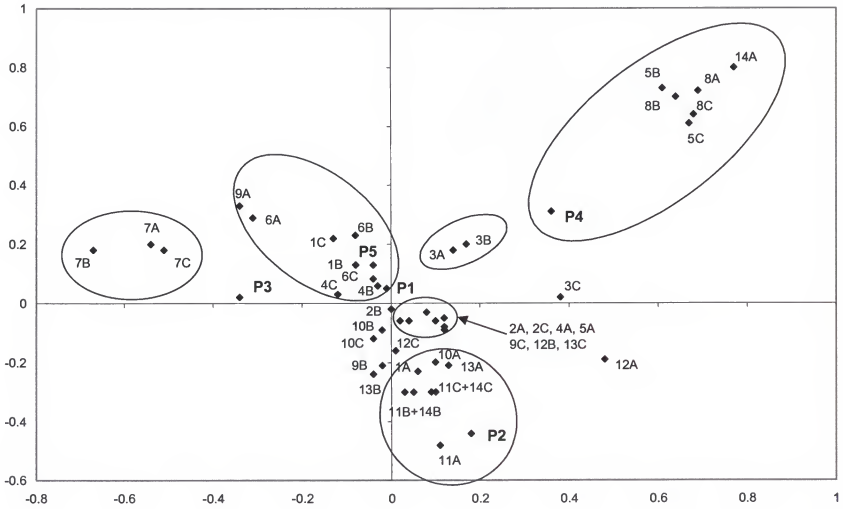
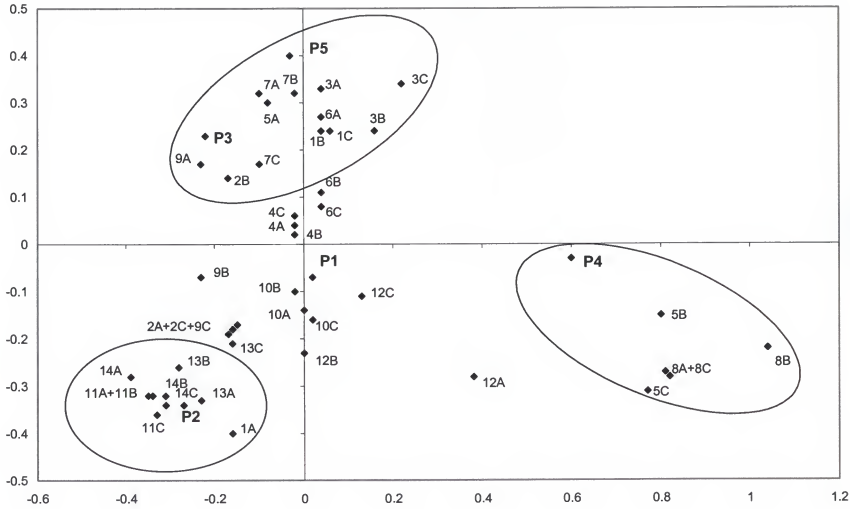

1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
14A
5B
8A
8B
8C
5C
P4
9A
6A
7A
6B
1C
3B
3A
P5
7B
7C
1B
6C
4C
4B
P1
P3
3C
2B
10B
2A, 2C, 4A, 5A
9C, 12B, 13C
10C
12C
12A
10A
9B
1A
13A
13B
11C+14C
11B+14B
P2
11A

Figure 5-8. Simple correspondence analysis from 1999 to establish the relationship between the parts of the plant and the incidence of specific fungi isolated from three different cultivars of peanut. The variables P1 through P5 represent the five parts of the plant from which fungi were isolated. The total plant is represented by P1, hypocotyls by P2, roots by P3, pegs by P4. and the pods by P5. The letters A, B, and C represent the cultivar of peanut from which the isolations were made. The cultivar 'Florunner' is represented by A, the cultivar 'Florida MDR 98' by B, and the cultivar 'Georgia Green' by C. The fungi are represented as follows: *Aspergillus flavus* (1), *Aspergillus niger* (2), *Cylindrocladium parasiticum* (3), *Fusarium* spp. (4), *Lasiodiplodia theobromae* (5), *Macrophomina phaseolina* (6), *Neocosmospora vasinfecta* (7), *Phomopsis* sp. (8), *Pythium* spp. (9), *Rhizoctonia solani* (10), *Rhizopus* spp. (11), *Sclerotium rolfsii* (12), *Trichoderma* spp. (13), and *Zygorhynchus* sp. (14). Units on the horizontal and vertical axes were not defined when the results from correspondence analysis were plotted.


0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
P5
P3
P1
P4
P2
7A
7B
3A
3C
5A
6A
3B
1B
1C
9A
7C
2B
6B
4C
6C
4A
4B
9B
10B
12C
10A
10C
2A+2C+9C
13C
12B
14A
13B
11A+11B
14B
14C
13A
11C
1A
5B
8B
8A+8C
12A
5C

Phomopsis sp. (8A, B, C) from all three cultivars and *L. theobromae* from Florida MDR 98 and Georgia Green (5B, C) were closely associated with the pegs (P4) of the plant. *Neocosmospora vasinfecta* (7A, B, C), *M. phaseolina* (6A, B, C), *Pythium* spp. from Florunner (9A) and *A. flavus* from Florida MDR 98 and Georgia Green (1B, C) tended to be associated disproportionately with the pods (P5), roots (P3), or both. In 1998, the incidence of *C. parasiticum* (3A, B, C) was more closely associated with the pods (P5) and the pegs (P4), while in 1999 the pathogen was more closely associated with the pods (P5) and the roots (P3). *Rhizopus* spp. (11A, B, C), *Zygorhynchus* spp. (14A, B, C), and *Trichoderma* spp. (13A, B, C) tended to be associated disproportionately with the hypocotyls (P2). It is difficult to associate *S. rolfsii* (12A, B, C) with a specific cluster of fungi; however, in both 1998 and 1999, this fungus was more closely associated with the pegs and the hypocotyls, and less associated with the roots or the pods.

The patterns of fungal incidence in association with the parts of the peanut plant were similar between 1998 and 1999 (Figures 5-7 and 5-8). The most important difference was that in 1999, fungi most closely associated with the roots and the pods were better differentiated from the origin than they were in 1998. This was largely the result of the greater distance from the origin of the fungi associated with the pegs (*L. theobromae* and *Phomopsis* sp.) which led to a compression of the vertical scale in 1998.

When isolated from Florunner, the fungal pathogens *L. theobromae*, *R. solani*, *Pythium* spp., *C. parasiticum,* and *S. rolfsii* were associated with the most severe symptoms of disease (Figures 5-9 and 5-10). These same pathogens

Figure 5-9. Simple correspondence analysis from 1998 to establish the relationship between the health rating given to each sampled plant and the incidence of specific fungi isolated from three different cultivars of peanut. The variables R1 through R5 represent the five health ratings given to the plant from which fungi were isolated. A symptomless plant is represented by R1. Plants with discoloration or restricted lesions are represented by R2. The plants with expanding lesions and slight wilt are represented by R3. The plants with more substantial wilt and some necrotic tissue are represented by R4. The plants with severe wilt and necrosis to the point of death are represented by R5. The letters A, B, and C represent the cultivar of peanut from which the isolations were made. The cultivar 'Florunner' is represented by A, the cultivar 'Florida MDR 98' by B, and the cultivar 'Georgia Green' by C. The fungi are represented as follows: *Aspergillus flavus* (1), *Aspergillus niger* (2), *Cylindrocladium parasiticum* (3), *Fusarium* spp. (4), *Lasiodiplodia theobromae* (5), *Macrophomina phaseolina* (6), *Neocosmospora vasinfecta* (7), *Phomopsis* sp. (8), *Pythium* spp. (9), *Rhizoctonia solani* (10), *Rhizopus* spp. (11), *Sclerotium rolfsii* (12), *Trichoderma* spp. (13), and *Zygorhynchus* sp. (14). Units on the horizontal and vertical axes were not defined when the results from correspondence analysis were plotted.

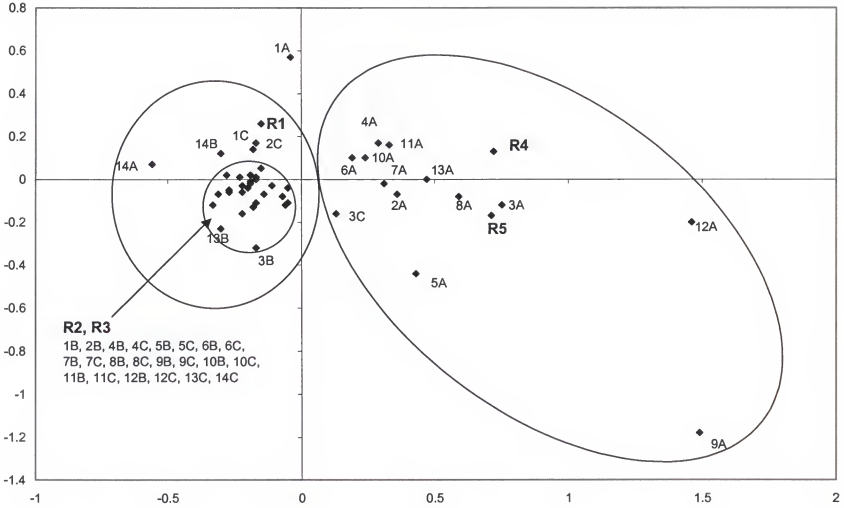
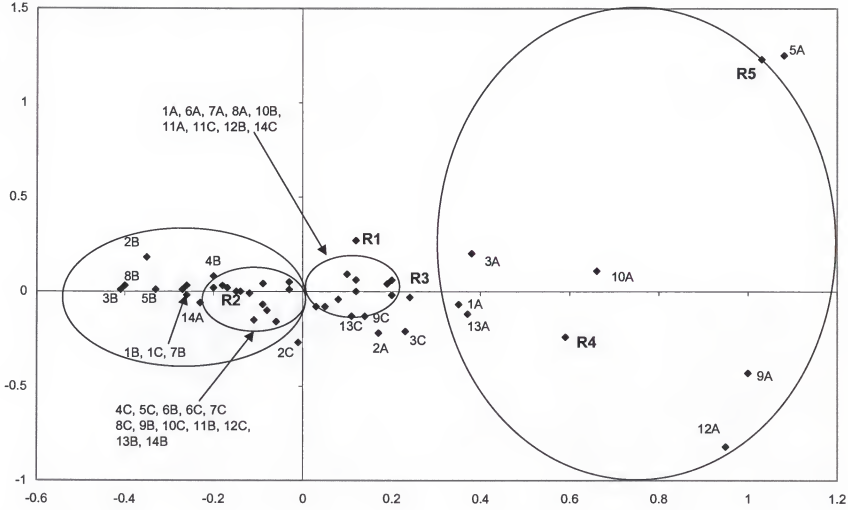

0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1
-0.5
0
0.5
1
1.5
2
1A
R1
1C
2C
14B
14A
4A
11A
R4
10A
6A
7A
13A
2A
8A
3A
3C
R5
12A
13B
3B
5A
9A
R2, R3
1B, 2B, 4B, 4C, 5B, 5C, 6B, 6C,
7B, 7C, 8B, 8C, 9B, 9C, 10B, 10C,
11B, 11C, 12B, 12C, 13C, 14C

Figure 5-10. Simple correspondence analysis from 1999 to establish the relationship between the health rating given to each sampled plant and the incidence of specific fungi isolated from three different cultivars of peanut. The variables R1 through R5 represent the five health ratings given to the plant from which fungi were isolated. A symptomless plant is represented by R1. Plants with discoloration or restricted lesions are represented by R2. The plants with expanding lesions and slight wilt are represented by R3. The plants with more substantial wilt and some necrotic tissue are represented by R4. The plants with severe wilt and necrosis to the point of death are represented by R5. The letters A, B, and C represent the cultivar of peanut from which the isolations were made. The cultivar 'Florunner' is represented by A, the cultivar 'Florida MDR 98' by B, and the cultivar 'Georgia Green' by C. The fungi are represented as follows: *Aspergillus flavus* (1), *Aspergillus niger* (2), *Cylindrocladium parasiticum* (3), *Fusarium* spp. (4), *Lasiodiplodia theobromae* (5), *Macrophomina phaseolina* (6), *Neocosmospora vasinfecta* (7), *Phomopsis* sp. (8), *Pythium* spp. (9), *Rhizoctonia solani* (10), *Rhizopus* spp. (11), *Sclerotium rolfsii* (12), *Trichoderma* spp. (13), and *Zygorhynchus* sp. (14). Units on the horizontal and vertical axes were not defined when the results from correspondence analysis were plotted.


1.5
1
0.5
0
-0.5
-1
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
1A, 6A, 7A, 8A, 10B,
11A, 11C, 12B, 14C
1B, 1C, 7B
4C, 5C, 6B, 6C, 7C
8C, 9B, 10C, 11B, 12C,
13B, 14B
R1
R2
R3
R4
R5
2B
4B
8B
3B
5B
14A
2C
13C
9C
2A
3C
3A
10A
1A
13A
5A
9A
12A

were associated with less severe symptoms when isolated from Florida MDR 98 and Georgia Green. The five different health ratings were represented by the symbols R1 through R5, where a rating of R1 was given to a plant without any symptoms of disease and a rating of R5 was given to a dead plant or one with the most severe necrosis or wilt. In both figures, the position of the health ratings was best defined along the horizontal axis from left to right. The position of R1 represented the healthiest plants and deviated from the otherwise linear relationship in both 1998 and 1999. Most fungi from all cultivars were not associated with severe symptoms of disease.

There were no consistent significant differences ($\alpha = 0.1$) in the incidences of *A. flavus*, *A. niger*, *Fusarium* spp., *L. theobromae*, *M. phaseolina*, *N. vasinfecta*, *Pythium* spp., *S. rolfsii*, *Trichoderma* spp., or *Zygorhynchus* sp. among cultivars over sequential growth stages (Figures 5-11, 5-12, 5-14 to 5-17, 5-19, 5-22 to 5-24). In 1998, the incidences of *R. solani*, *C. parasiticum*, and *Phomopsis* sp. were lower in Florida MDR 98 than in Florunner, though the reduction in incidences of these fungi were less evident in 1999 (Figures 5-13, 5-18, 5-20). The incidence of *Rhizopus* spp. was significantly greater in Florida MDR 98 and Georgia Green than in Florunner in 1998 (Figure 5-21).

The incidences of some fungi continued to increase throughout the season. For example, in 1999, the incidence of *A. niger* in all cultivars continued to increase from the beginning of the season until harvest, though this pattern was not observed in 1998 (Figure 5-12). A similar trend was observed in both 1998 and 1999 for the incidences of *C. parasiticum* (Figure 5-13) and

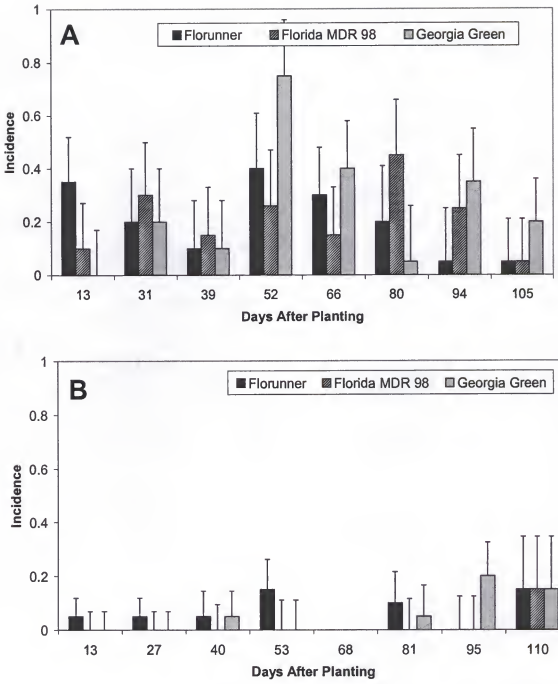


Figure 5-11. Incidence of *Aspergillus flavus* measured as the proportion of infected plants that were sampled from three cultivars of peanut at the North Florida Research and Education Center, Quincy, in 1998 (A) and 1999 (B). The mean incidence was calculated by analysis of variance; error bars represent the results of mean separation by least significant difference at the $\alpha = 0.1$ level. Error bars represent differences on a single date.

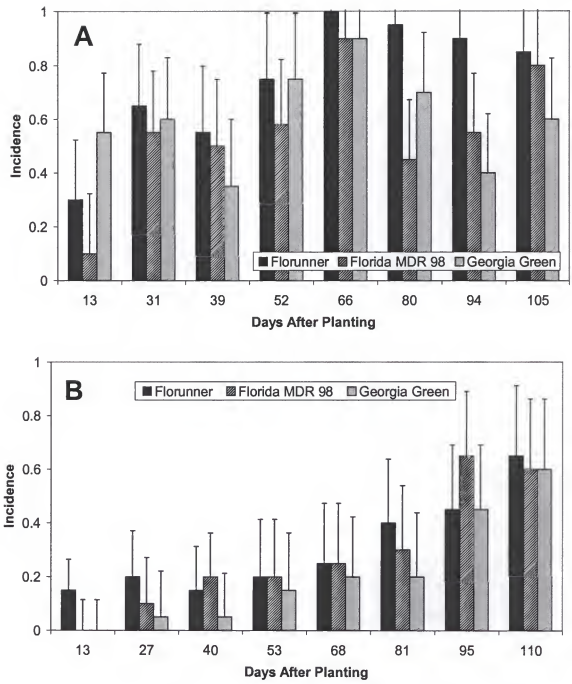


Figure 5-12. Incidence of *Aspergillus niger* measured as the proportion of infected plants that were sampled from three cultivars of peanut at the North Florida Research and Education Center, Quincy, in 1998 (A) and 1999 (B). The mean incidence was calculated by analysis of variance; error bars represent the results of mean separation by least significant difference at the $\alpha = 0.1$ level. Error bars represent differences on a single date.

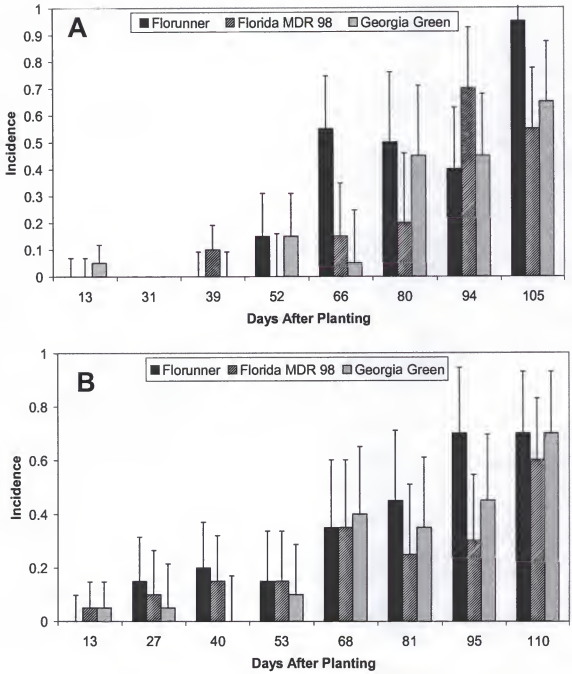


Figure 5-13. Incidence of *Cylindrocladium parasiticum* measured as the proportion of infected plants that were sampled from three cultivars of peanut at the North Florida Research and Education Center, Quincy, in 1998 (A) and 1999 (B). The mean incidence was calculated by analysis of variance; error bars represent the results of mean separation by least significant difference at the α= 0.1 level. Error bars represent differences on a single date.

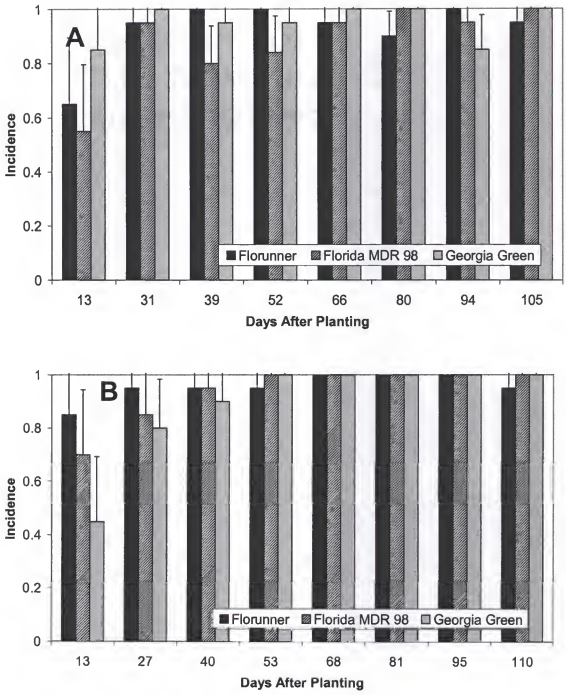


Figure 5-14. Incidence of *Fusarium* spp. measured as the proportion of infected plants that were sampled from three cultivars of peanut at the North Florida Research and Education Center, Quincy, in 1998 (A) and 1999 (B). The mean incidence was calculated by analysis of variance; error bars represent the results of mean separation by least significant difference at the $\alpha = 0.1$ level. Error bars represent differences on a single date.

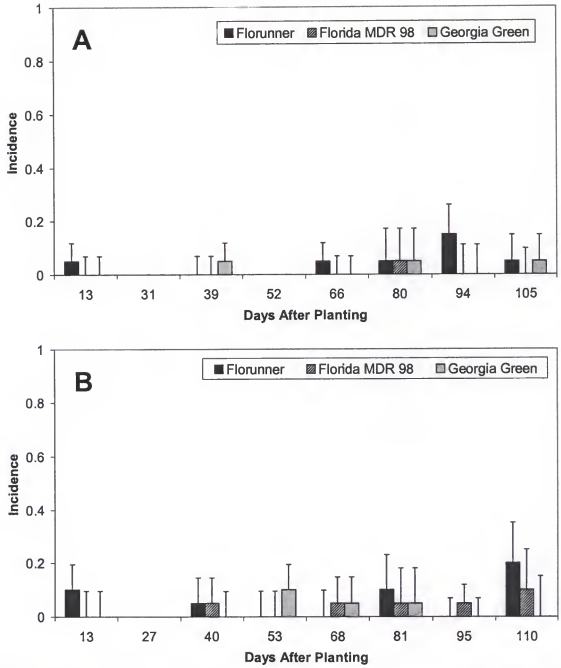


Figure 5-15. Incidence of *Lasiodiplodia theobromae* measured as the proportion of infected plants that were sampled from three cultivars of peanut at the North Florida Research and Education Center, Quincy, in 1998 (A) and 1999 (B). The mean incidence was calculated by analysis of variance; error bars represent the results of mean separation by least significant difference at the $\alpha = 0.1$ level. Error bars represent differences on a single date.

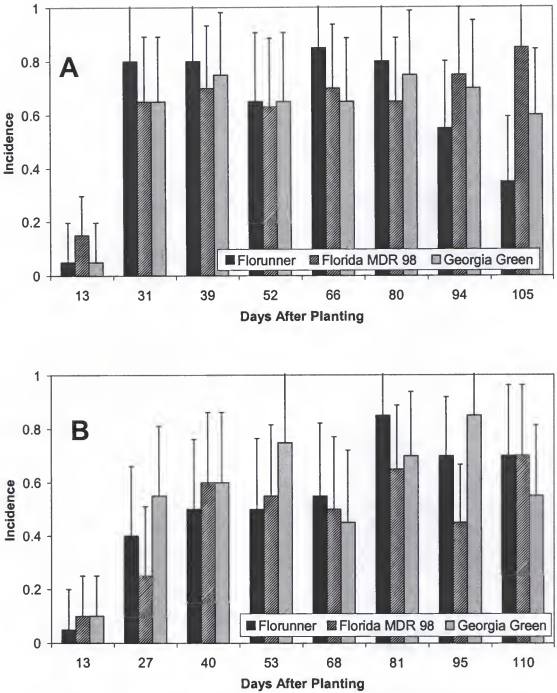


Figure 5-16. Incidence of *Macrophomina phaseolina* measured as the proportion of infected plants that were sampled from three cultivars of peanut at the North Florida Research and Education Center, Quincy, in 1998 (A) and 1999 (B). The mean incidence was calculated by analysis of variance; error bars represent the results of mean separation by least significant difference at the $\alpha = 0.1$ level. Error bars represent differences on a single date.

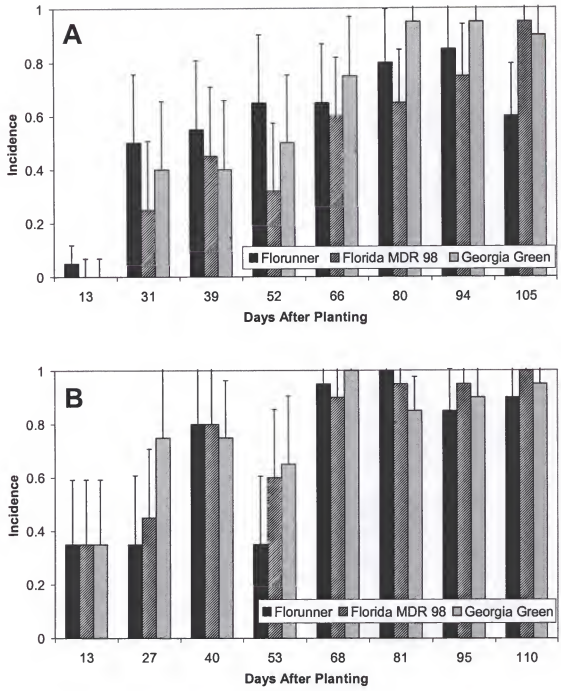


Figure 5-17. Incidence of *Neocosmospora vasinfecta* measured as the proportion of infected plants that were sampled from three cultivars of peanut at the North Florida Research and Education Center, Quincy, in 1998 (A) and 1999 (B). The mean incidence was calculated by analysis of variance; error bars represent the results of mean separation by least significant difference at the α= 0.1 level. Error bars represent differences on a single date.

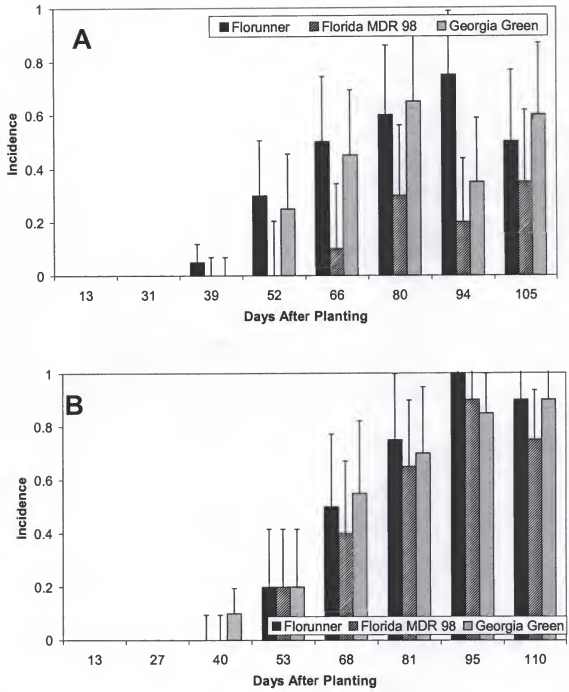


Figure 5-18. Incidence of *Phomopsis* sp. measured as the proportion of infected plants that were sampled from three cultivars of peanut at the North Florida Research and Education Center, Quincy, in 1998 (A) and 1999 (B). The mean incidence was calculated by analysis of variance; error bars represent the results of mean separation by least significant difference at the $\alpha = 0.1$ level. Error bars represent differences on a single date.

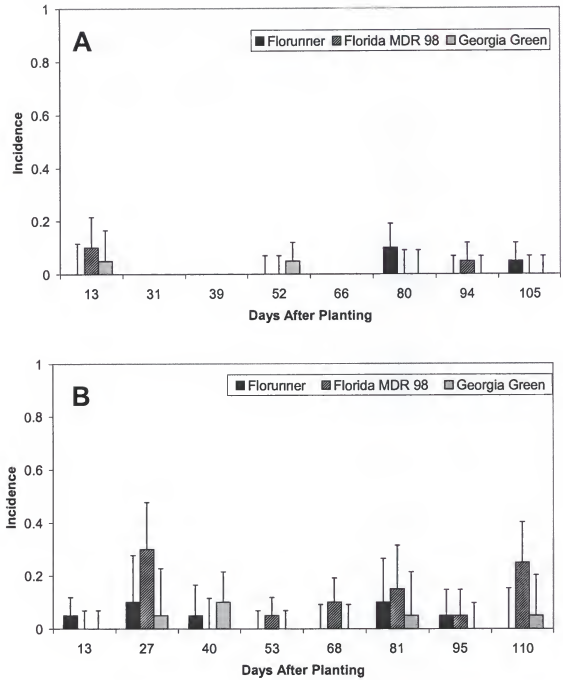


Figure 5-19. Incidence of *Pythium* spp. measured as the proportion of infected plants that were sampled from three cultivars of peanut at the North Florida Research and Education Center, Quincy, in 1998 (A) and 1999 (B). The mean incidence was calculated by analysis of variance; error bars represent the results of mean separation by least significant difference at the α= 0.1 level. Error bars represent differences on a single date.

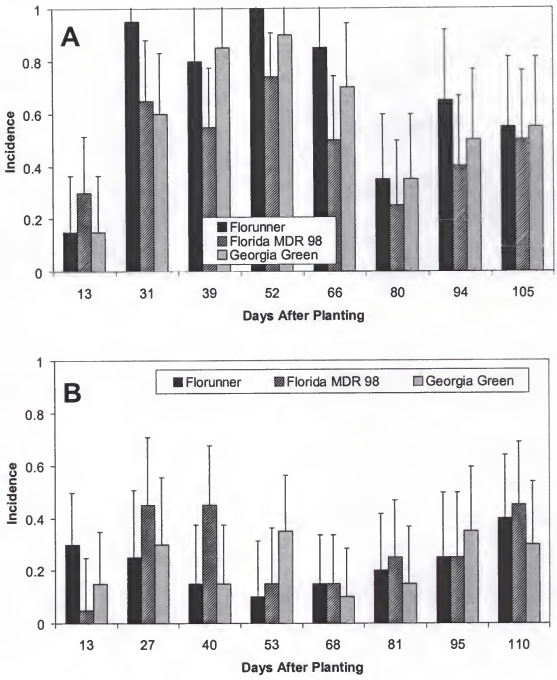


Figure 5-20. Incidence of *Rhizoctonia solani* measured as the proportion of infected plants sampled from three cultivars of peanut at the North Florida Research and Education Center, Quincy, in 1998 (A) and 1999 (B). The mean incidence was calculated by analysis of variance; error bars represent the results of mean separation by least significant difference at the $\alpha = 0.1$ level. Error bars represent differences on a single date.

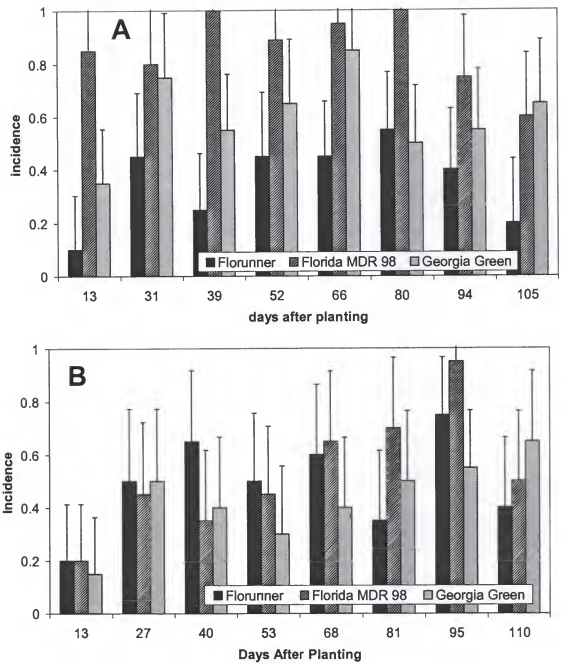


Figure 5-21. Incidence of *Rhizopus* spp. measured as the proportion of infected plants that were sampled from three cultivars of peanut at the North Florida Research and Education Center, Quincy, in 1998 (A) and 1999 (B). The mean incidence was calculated by analysis of variance; error bars represent the results of mean separation by least significant difference at the α= 0.1 level. Error bars represent differences on a single date.

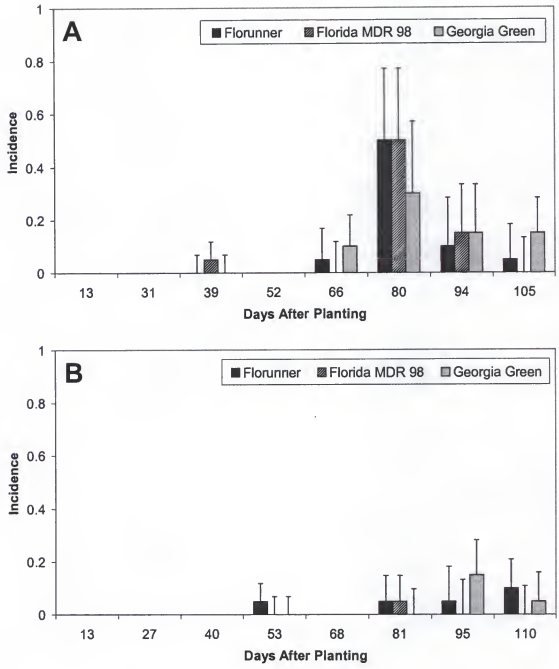


Figure 5-22. Incidence of *Sclerotium rolfsii* from three cultivars of peanut planted at the North Florida Research and Education Center near Quincy, Florida in 1998 (A) and 1999 (B). The mean incidence was calculated using analysis of variance; error bars represent the results of mean separation using least significant difference at the $\alpha = 0.1$ level. Error bars represent differences on a single date.

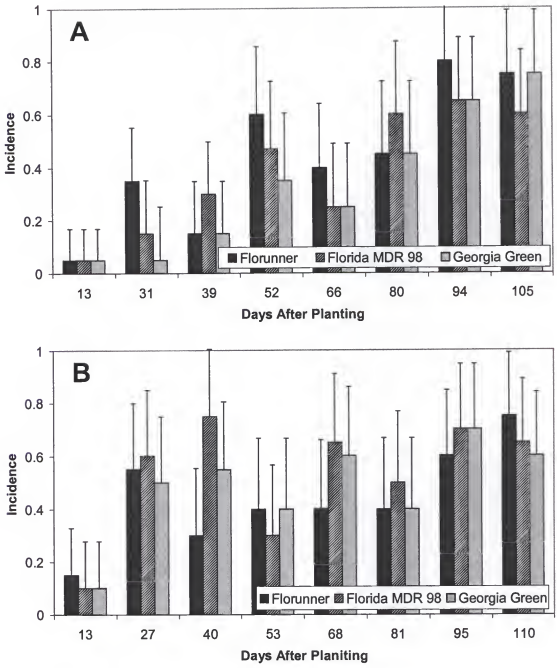


Figure 5-23. Incidence of *Trichoderma* spp. measured as the proportion of infected plants that were sampled from three cultivars of peanut at the North Florida Research and Education Center, Quincy, in 1998 (A) and 1999 (B). The mean incidence was calculated by analysis of variance; error bars represent the results of mean separation by least significant difference at the α= 0.1 level. Error bars represent differences on a single date.

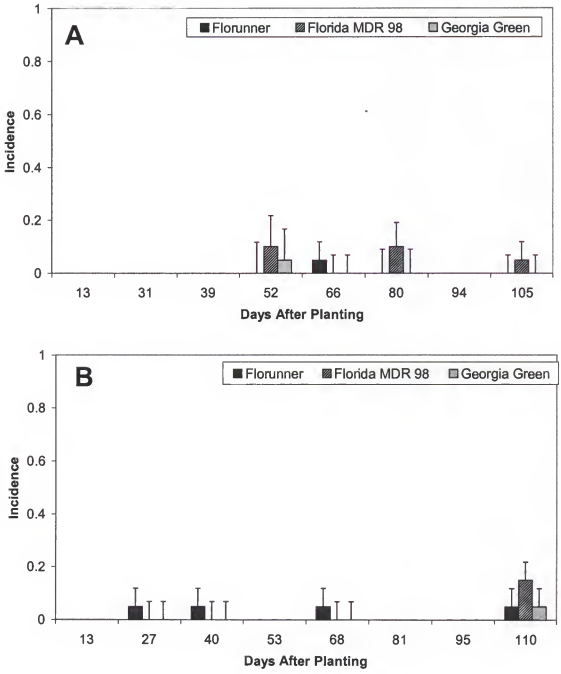


Figure 5-24. Incidence of *Zygorhynchus* sp. measured as the proportion of infected plants that were sampled from three cultivars of peanut at the North Florida Research and Education Center, Quincy, in 1998 (A) and 1999 (B). The mean incidence was calculated by analysis of variance; error bars represent the results of mean separation by least significant difference at the α= 0.1 level. Error bars represent differences on a single date.

Phomopsis sp. (Figure 5-18) and in 1998 for the incidence of *N. vasinfecta* (Figure 5-17).

Discussion

Peanut plants were sampled throughout the 1998 and 1999 growing seasons. The sequential sampling dates corresponded with two vegetative stages, an early reproductive growth stage, and progressive stages of pod and seed development (Table 5-1). The growth stages among cultivars were similar at each sampling date, though there were periods when the development of Florida MDR 98 lagged behind that of Florunner and Georgia Green (Table 5-1). This was not unexpected as Florida MDR 98 is reported to mature 2 weeks later than Florunner (183).

Yield

The cultivar with the largest yields each year was Florida MDR 98, and there was no significant difference between the yields of Florunner and Georgia Green (Table 5-2). These results were complicated by the late harvest of Florunner and Georgia Green in 1998 and the severity of leaf spot and TSWV that affected these two cultivars in 1999. The reduced yields for these two cultivars cannot be attributed solely to differences in levels of soilborne disease.

Disease Severity

Although diseases other than those caused by soilborne fungal pathogens may have been a factor in the reduced yields, Florunner had greater severities of soilborne disease than did Florida MDR 98 or Georgia Green in 1998. Based on the signs and symptoms present on the wilted plants, most of the disease was

either southern stem blight, caused by *S. rolfsii* or Cylindrocladium black rot, caused by *C. parasiticum*. In 1998, the AUDPC values and the apparent infection rates for Florida MDR 98 and Georgia Green were significantly lower than the values for Florunner. In 1999, the AUDPC value for Florida MDR 98 was significantly lower than in Florunner. The values of the AUDPC were not significantly between Georgia Green and Florunner or Florida MDR 98 during 1999.

Much of the wilt that was observed in 1999 was associated with TSWV and was not included in this analysis. The reduced amount of wilt to soilborne disease in the second year may have been the result of the later planting date and the lack of complete development of the foliar canopy. The peanuts in both years were grown in the same field and inoculum of the fungal pathogens remained high based on results from the extraction of microsclerotia of *C. parasiticum* from the soil (results not presented). Without the fully developed foliar canopy, the microclimate at the crown and in the pegging zone may have been less conducive for the development of disease, even though *A. niger, C. parasiticum, R. solani*, and *S. rolfsii* were isolated (Figures 5-12, 5-13, 5-20, and 5-22).

Foliar Canopy

The development of the foliar canopy may play an important role in the formation of the tertiary stage of the general community of soilborne fungi. In 1998, the foliar canopy of Florunner had closed by 80 days after planting and produced an unbroken spread of foliage across most of the whole plots (Figure

5-1). By 94 days after planting, the canopy had completely closed for Florida MDR 98 and Georgia Green. In 1999, the canopy did not close completely for any of the cultivars and may have been affected by the planting date and the growing conditions later in the season. Poorly developed canopies and reduced yields were also attributed to later planting dates in a study of aflatoxigenic fungi in Alabama (165).

Soil temperatures measured at a depth of 10 cm within the peanut rows were affected by the development and closure of the canopy during a study in North Carolina (156). In 1985, the hours per day in which the soil temperature exceeded 28° C decreased as the canopy approached closure, and, in 1986, the soil temperature declined after the canopy closed (156). The soil generally stayed warmer for longer periods of time after the canopy had closed in raised peanut beds than in flat rows. The increased soil temperatures that were associated with the raised beds were believed to inhibit the development of Cylindrocladium black rot and could protect pods from rot (156).

During 1999, soil temperatures within the pegging zone and temperatures within the canopy declined as the canopy developed (Figure 5-2). The relative humidity within the canopy also increased as the canopy developed, but decreased at the end of the season (Figure 5-3). Sanders et al. (150) found that the temperature in the canopies of irrigated peanuts were approximately 7° C cooler than those that were stressed by drought. The structure of a well-irrigated canopy was probably greater than a canopy under drought stress. These

researchers also believed that there was a strong influence of temperatures in the canopy on the ambient temperature of the pods (150).

In the present study, the incidences of pathogens, such as *S. rolfsii* and *C. parasiticum,* increased as the canopy closed while the incidences of other pathogens that emerged prior to the tertiary stage, such as *R. solani* and *A. niger*, were not associated with this event (Figures 5-12, 5-13, 5-20, and 5-22). Cooler soil temperatures have been associated with greater severity of Cylindrocladium black rot and high moisture and a well developed foliar canopy have been associated with increased severity of southern stem rot (137, 154). The emergence of the *S. rolfsii* and *C. parasiticum* during the tertiary stage of development of the general community was likely related to the environmental changes that occurred as the foliar canopy developed.

Differences in Fungal Incidence Associated with Different Cultivars

Research to evaluate the partial resistance of peanut cultivars to soilborne diseases such, as Cylindrocladium black rot, southern stem rot, and Diplodia collar rot has not been uncommon (28, 58, 139, 163). However, there is less information available in the literature to document differences in the incidences of soilborne fungi isolated from different cultivars. In Oklahoma, the cultivars Florigiant and NC-7 were more susceptible to pod rot caused by *P. myriotylum* than were the cultivars Pronto, Spanco, Okrun, Langley, GK-7, or Florunner (116). However, the incidences of *Pythium* spp. in the roots of these cultivars were not different from each other. In another study, *C. parasiticum* infected

Florigiant, a cultivar susceptible to Cylindrocladium black rot, at significantly higher levels than it infected the partially resistant cultivar Spancross (175).

Baird et al. (14) found some differences between the mycoflora of pods harvested from the cultivars Florunner and Southern Runner. However, the results were not consistent for different planting dates, under different fungicide programs, and in different fields. The incidences of *Fusarium solani*, *Fusarium* spp., *L. theobromae*, and *Rhizopus* spp. were greater on pods from Southern Runner that had been treated with the fungicide flutolanil than on pods from Florunner that had also been treated with the fungicide.

Finally, Jackson (99) studied the fungi that colonized the pods of three cultivars of peanut, Argentine, Early Runner, and Florigiant. Although he isolated a number of different fungi and identified several fungal communities, Jackson (99) found that the estimated numbers of all fungi on the pods and kernels were not statistically different among cultivars. However, he noted that there were slight differences among the cultivars in the composition of the fungal communities. For example, in the cultivar Argentine, *Chaetomium* sp. was important in the endocarpic community of immature kernels while in Early Runner and Florigiant, *Thielavia* sp. was more important.

In the present study, the incidences *A. flavus, A. niger, Fusarium* spp., *L. theobromae, M. phaseolina, N. vasinfecta, Pythium* spp., *S. rolfsii, Trichoderma* spp., and *Zygorhynchus* sp. were not consistently different among the cultivars at sampling dates throughout the season (Figures 5-11, 5-12, 5-14 to 5-17, 5-19, 5-22, to 5-24). While Baird et al. (14) found lower incidences of *L. theobromae* and

Fusarium spp. in pods from Florunner than in pods from Southern Runner, a parent of Florida MDR 98, similar differences were not observed among the cultivars in this study. Though Florida MDR 98 is reported to have some resistance to southern stem blight, the incidence of *S. rolfsii* was not reduced in this cultivar when compared to Florunner (183). Differences in the incidences of these fungi at a single sampling date were likely the result of the sampling errors associated with soilborne microorganisms rather than a true biological effect related to the cultivar.

The incidences of some fungi were affected by the cultivar of peanut from which they were isolated. These included *C. parasiticum, Phomopsis* sp., *R. solani*, and *Rhizopus* spp. (Figures 5-13, 5-18, 5-20, and 5-21). The differences were most obvious between Florunner and Florida MDR 98 and, with the exception of *C. parasiticum*, were apparent only in 1998. Again, the differences in planting dates and the development of the canopy between 1998 and 1999 may have influenced these results. In 1998, the incidence of *C. parasiticum*, *Phomopsis* sp., and *R. solani* were significantly lower in Florida MDR 98 than in Florunner during a part of the season. In 1998, the incidence of *Rhizopus* spp. was significantly greater on Florida MDR 98 than on Florunner and Georgia Green during the early part of the season. As *Rhizopus* spp. can be seed-borne, the seed for Florida MDR 98 may have been infected prior to planting (123, 124). From the study by Baird et al. (14), the incidence of *Rhizopus* spp. was occasionally greater in Southern Runner than in Florunner. Southern Runner is

a parent of Florida MDR 98, so there may be a link between colonization by *Rhizopus* spp. and these two cultivars (183).

In 1998, the incidence of *C. parasiticum* was significantly greater in Florunner than in Florida MDR 98 at 66 and 80 days after planting and significantly greater than in Georgia Green at 66 days after planting. This trend was less obvious in 1999, though the incidence of *C. parasiticum* was significantly lower in Florida MDR 98 at 95 days after planting than it was in Florunner. In 1998, the incidence of soilborne disease in both Florida MDR 98 and Georgia Green may have been delayed by later infection of these plants by *C. parasiticum*. Culbreath et al. (58) found that delays in the onset of epidemics of Cylindrocladium black rot were important to explain differences in disease severity between susceptible genotypes and those with partial resistance. Also, *Fusarium* spp. were more commonly isolated from the cortex and stele of a cultivar with partial resistance to Cylindrocladium black rot than one that was susceptible (175). The researchers questioned the importance of the incidence of *Fusarium* spp. to partial resistance. This did not occur in Quincy, as the incidences of *Fusarium* spp. were high for all cultivars (Figure 5-14).

In both 1998 and 1999, there was a general trend for the incidence of *R. solani* to decline in the middle of the season (Figure 5-20). This decline appears to be significant and not to be the result of sampling errors based on the following observations. The trend occurred in all cultivars in both 1998 and 1999. In all cultivars, the incidence increased again at the end of the season. *Rhizoctonia solani* is a causal agent of the seed rot, and root and hypocotyl rot of

seedlings (31). As the hypocotyl matures, it becomes hardened and indistinguishable from the taproot and may become less suitable for colonization. Development of the pegs and pods later in the season provides additional tissue for colonization. Harris and Moen (88) found that in wheat, attack by *R. solani* was confined to the juvenile tissues of the seedlings and was rarely recovered from plants after they reached the tillering stage. These researchers found that the failure of the pathogen to persist on the wheat plants was unrelated to competition from other soilborne mycoflora.

The incidence of *S. rolfsii* was not significantly different among cultivars during 1998 or 1999 (Figure 5-22). This does not mean that the severity of southern stem blight was the same for all three of the cultivars, but differences in yields and the severity of soilborne disease may be more closely related to another pathogen.

Natural Associations of Soilborne Fungi

A primary objective in this study was to determine if the two communities of soilborne fungi identified in earlier surveys were affected by different cultivars of peanut. As noted earlier, Jackson (99) found that the composition of fungal communities varied slightly between peanut cultivars. A general community of soilborne fungi is associated with the peanut plant and its diversity increased through at least three stages of development (Chapter 4). The fungi that make up this community could be grouped based upon the conditions upon which they attained some relative abundance. The development of the general community, as defined in Chapter 4, included the foundational, secondary, and tertiary

stages. The second peg-community emerged later in the season with the tertiary stage and contained fungi that may be associated with foliar diseases.

The foundational stage of the general community occurred very early in the season and contained fungi that rapidly colonized the young seedlings. The fungi that formed the community at this time normally maintained high incidences throughout the season, and would commonly infect the roots, hypocotyls, pegs, and pods as they developed. Fungi included in this stage of development based upon the survey of commercial fields included *Fusarium* spp., *Penicillium* spp., *Trichoderma* spp., and *A. niger*.

The secondary stage of the general community began to develop while the peanut plant was still in the vegetative growth stages and included fungi that were more closely associated with the roots, pods, and pegs, than with the hypocotyls. The incidences of these fungi were often lower than that of those identified with the foundational stage. Based upon the results from the general surveys, fungi that became established in the community during the secondary stage included *R. solani*, *N. vasinfecta*, and *M. phaseolina*.

The tertiary stage in the development of the general community began later in the season and was associated with the development of the pods, the pegs, and the closure of the canopy. Fungi that became a part of the community during this stage were associated with the roots, pods, and pegs. Fungi included in this group were *C. parasiticum*, *Pythium* spp., *L. theobromae*, and *Zygorhynchus* sp.

The peg community emerged with the tertiary stage, but its members were isolated predominantly, though not exclusively, from the pegs alone. Fungi that formed this community included *Phomopsis* sp. and *S. rolfsii, Nigrospora* sp., *Mucor* spp., *Leptosphaerulina* sp., *Choanephora cucurbitarum* and perhaps *Alternaria* sp. and *Phoma* sp.

The incidences of some fungi that belonged to the general community of soilborne fungi were not clearly associated with a particular growth stage, though they may have been more closely associated with the hypocotyls than were other fungi. Fungi placed in this group included *Rhizopus* spp., *Cunninghamella* sp., and *A. flavus.*

Based upon the results presented in Figures 5-11 through 5-24, the general trends for the changes in incidences for these 14 fungi over a season were similar among the three cultivars of peanut, with the exception of the incidence of *Rhizopus* spp. on Florida MDR 98 in 1998 (Figure 5-21). *Rhizopus* spp. may be seed-borne and the high incidence of this fungus on Florida MDR 98 early in 1998 was an indication that the fungus may have been present at planting (140). Therefore, the cultivar of peanut did not appear to affect either the stage at which these fungi emerged in the general community or in the peg community.

The relationships between these 14 fungi and the development of the communities of soilborne fungi are further elucidated in Figures 5-5 and 5-6. Based upon the results from correspondence analysis alone, it was difficult to differentiate the fungi associated with the foundational stage of the general

community from those in the secondary stage. Each figure contained two major groups of fungi. Those positioned near the origin were indicative of the fungi that would be included with the foundational and secondary stages of the general community, while those associated with the later growth stages (T6-T8) tended to be associated with the tertiary stage of development and with the peg community. The incidences of *A. flavus*, *L. theobromae*, *Pythium* spp., *S. rolfsii*, and *Zygorhynchus* sp. were very low in at least one of the seasons. Differences among cultivars for these fungi on the plots created with correspondence analysis were likely the result of sampling error associated with naturally low incidences.

The relationships between the incidences of soilborne fungi and the part of the plant from which they were isolated are presented in Figures 5-7 and 5-8. A large number of points were positioned around the origin, which indicated a general distribution of these fungi in all parts of the plant. Natural groupings also occurred in association with the pegs, the roots, the pods, and the hypocotyls.

Few trends that concerned the composition of the communities of soilborne fungi associated with each cultivar were detected (Figures 5-5 through 5-8). *Phomopsis* sp. remained the only member of the peg community, though in this study, *L. theobromae* in Florida MDR 98 and Georgia Green was more closely associated with the pegs than was *L. theobromae* in Florunner. In this study, *S. rolfsii* would not be included in the peg community because it was more generally distributed within the plant and would be included with the tertiary stage in the development of the general community. However, the incidence of

S. rolfsii was more closely associated with the pegs and the hypocotyls than it was with either the roots or the pods. This may have occurred because diseased tissue from the crown was included with the hypocotyl tissues for analysis in 1998 and 1999, while in 1995 and 1996, this tissue was not examined.

The tertiary stage in the development of the general community was composed of *C. parasiticum*, *L. theobromae*, and *S. rolfsii.* In 1998, the incidences of *N. vasinfecta* and *Trichoderma* spp. were positioned near the end of the season; however they clearly belonged to the foundational or secondary stages rather than to the tertiary stage of community development. These fungi were well established earlier in the season; their placement with correspondence analysis was the result of an increase in incidence at the end of the season (Figures 5-17 and 5-23). In 1999, the incidences of *A. niger* were associated with the end of the season, which may be explained by the late planting date and the temperatures during this portion of the season. The association of *Trichoderma* sp. with hypocotyls and the general association of *A. niger* with all parts of the plant were evidence that these fungi belonged to the earlier stages of development.

Based upon the descriptions of the fungi associated with the foundational and secondary stages of community development, the following fungi would be placed into these groups: *Fusarium* spp., *M. phaseolina*, *N. vasinfecta*, *R. solani*, *Rhizopus* spp., *Trichoderma* spp., and *Zygorhynchus* sp. (Figures 5-5 to 5-8).

The low incidences of *Pythium* spp. and *A. flavus* made the placement of these fungi difficult.

Only *Fusarium* spp. appeared to be well established at the first sampling date, and thus, could be placed convincingly in the foundational stage of community development (Figures 5-11 through 5-24). *Trichoderma* spp. and *A. niger* would be better placed with the secondary stage of development, although the incidence of *Trichoderma* spp. had some association with the hypocotyls (Figures 5-7 and 5-8). *Macrophomina phaseolina*, *N. vasinfecta*, and *R. solani* were placed in the secondary stage of development.

The composition of the general community of soilborne fungi and the peg community in this study were not greatly affected by the cultivar of peanut. However, the compositions of fungi associated with each stage in the development of the general community of soilborne fungi in Quincy were less distinct than were those from the surveys in 1995 and 1996. The descriptions proposed in Chapter 4 were based upon information gathered from 24 commercial fields. The development of the community of soilborne fungi within a single field may be influenced by factors in addition to the growth stage of the host, such as inoculum density, that slightly affects the final result.

The Health of the Cultivar and the Incidences of Soilborne Fungi

The cultivars Florida MDR 98 and Georgia Green were generally healthier than Florunner based upon observations of each plant after sampling (Figures 5-9 and 5-10). The incidences of all of the fungi isolated from Florunner were skewed towards the more severe disease ratings of R4 and R5. The fungi from

Florunner that were associated with the greatest disease severity included *L. theobromae*, *Pythium* spp., *S. rolfsii*, *R. solani*, and *C. parasiticum*. In 1998, the incidence of *C. parasiticum* from Georgia Green (3C) was also associated with more severe symptoms. In 1999, a group, including *S. rolfsii* (12B) and *R. solani* (10B), from Florida MDR 98 and *C. parasiticum* (3C) and *Pythium* spp. (9C) from Georgia Green, tended to be associated with more severely diseased plants.

Conclusions

Yields from Florunner and Georgia Green were significantly less than those from Florida MDR 98. The severity of soilborne disease was significantly lower in Florida MDR 98 than it was in Florunner during both 1998 and 1999.

The incidences of most fungi were not different among the three cultivars of peanut that were assessed in this study. However, there was evidence that infection of Florida MDR 98 and Georgia Green by *C. parasiticum* was delayed as compared to infection of Florunner. This delay in infection and subsequent delay in an epidemic of Cylindrocladium black rot may have reduced the disease severity in Florida MDR 98.

Changes in temperature and relative humidity associated with the development of the foliar canopy in 1999 support the concept that conditions within the microclimate and the maturing of the pods and pegs played an important role in colonization of peanut by *C. parasiticum, S. rolfsii*, and *L. theobromae*.

The composition of the general community and the peg community of soilborne fungi was generally not affected by the cultivar of peanut and

supported the descriptions of community development based upon surveys from 1995 and 1996. However, it was more difficult to distinguish between the foundational and secondary stages of the general community with data from a single field than it was using data from multiple fields in 1995 and 1996. In the 1998-1999 studies, *S. rolfsii* would be included with the tertiary stage in the development of the general community rather than with the peg community based upon a more general distribution of the pathogen within the plant. The incidence of *L. theobromae* appeared to shift from a more general distribution within the plant in Florunner to a closer relationship with the pegs for Florida MDR 98 and Georgia Green. This was the most obvious difference in community composition among the three cultivars.

CHAPTER 6
FUNGICIDES AND THE INCIDENCE OF SOILBORNE FUNGI

Introduction

The varieties of peanuts that are grown in Florida are susceptible to a number of diseases caused by soilborne fungi. Some of the more important fungal diseases include seedling blights caused by *Rhizoctonia solani* and *Aspergillus niger*, Aspergillus crown rot caused by *A. niger*, Diplodia collar rot caused by *Lasiodiplodia theobromae*, limb rot caused by *R. solani*, southern stem blight caused by *S. rolfsii*, pod rot caused by *Pythium myriotylum*, and Cylindrocladium black rot caused by *Cylindrocladium parasiticum* (9, 20, 31, 55, 123, 138, 143).

Strategies to control these diseases often consist of an integration of cultural practices, such as choice of planting date and crop rotation, with the use of fungicides (114). Fungicides, such as tebuconazole and flutolanil, have been shown to be effective in the control of Rhizoctonia limb rot and southern stem blight (16, 30, 32, 33, 60, 70, 112, 148). Abound 2.08 FL is a fungicide that has been registered for use on peanut in Florida only recently, and it is also recommended for control of southern stem blight (114). Benomyl is recommended for the control of diseases caused by *A. niger*, Diplodia collar rot, and Cylindrocladium black rot. Tebuconazole is also recommended for the control of Cylindrocladium black rot (114, 126). These fungicides are normally

applied to the foliar canopy and washed by water to the crown of the plant and the soil surface via rainfall and irrigation.

From data collected in surveys of peanut fields in Florida during 1995 and 1996, 48 genera of soilborne fungi were isolated from the peanut plants. Many of these genera were associated with specific stages in the development of a community of fungi on the subterranean parts of the peanut plant. Because much of the data was collected in commercial fields where the grower determined the use of fungicides, the effect of fungicides on fungal incidence and the composition of the natural groupings was undetected. A better understanding of the influence of fungicide programs on the incidences of soilborne fungi in plants would be important in fungal ecology and for the control of fungal diseases.

The use of fungicides has been found to reduce natural populations of fungi. Applications of a combination of the fungicides captan, dinocap, benomyl, and methomyl on peach significantly reduced populations of fungi on the peach twigs (63). Fungi that were most affected by the applications of fungicides included *Alternaria* sp. and *Cladosporium* sp.; however populations of *Penicillium frequentans,* which is an antagonist of the pathogen *Molinia laxa, were not affected*. Applications of thiram, thiophanate-methyl, or agallol to rice reduced the diversity of fungi that were associated with the flowers and the developing seeds (115). Jacobi and Backman (100) found that a substitution of two applications of tebuconazole for chlorothalonil in programs for the control of leaf spot in peanut resulted in lower colonization of sound mature seed by *Aspergillus*

spp. The use of flutolanil has been associated with lower rates of isolation of *R. solani* from peanut pods (13).

One objective of this study was to determine if the incidences of 13 soilborne fungi were affected by the use of different fungicide programs. A second objective was to determine if differences in disease severity of the peanut crop could be related to changes in incidence of pathogenic fungi.

The fungicide treatments included applications of chlorothalonil, chlorothalonil plus benomyl, chlorothalonil plus tebuconazole, and chlorothalonil plus flutolanil. The incidences of the following fungi were evaluated throughout this 2-year study: *Aspergillus flavus, A. niger, C. parasiticum, Fusarium* spp., *L. theobromae, M. phaseolina, N. vasinfecta, Phomopsis* sp., *Pythium* spp., *R. solani, Rhizopus* spp., *S. rolfsii,* and *Trichoderma* spp. Most of these fungi were included because of reports that they are pathogens of peanut. *Fusarium* spp. has been linked to seedling wilts and the pod-rot complex (71). *Neocosmospora vasinfecta* is the causal agent of Neocosmospora foot rot and is observed fruiting on rotted pods collected from the soil (141, Kemerait, unpublished data). *Rhizopus stolonifer* has been associated with seedling blights (123). *Trichoderma* spp. are potentially useful in biological control of soilborne pathogens (53, 159, 182). *Phomopsis* sp. was included because of its preference for colonization of the pegs of the peanut plant: it was useful to observe whether or not these fungicide programs affected the tissue, such as the pegs, that is colonized by soilborne fungi.

Materials and Methods

The effect of fungicides on the incidence of soilborne fungi was evaluated during 1998 and 1999 near the town of Jay in Santa Rosa County, Florida. One grower farmed the two fields used in this study. The soil in each was naturally infested with *C. parasiticum* and *S. rolfsii,* along with other important soilborne fungi. In both fields, peanuts were rotated with 2 years of cotton. On 5 May 1998, the grower planted the cultivar ViruGard. The next year he planted Georgia Green on 1 May 1999. Peanuts were harvested on 29 August in 1998 and 8 September in 1999. The yields for each whole plot were assessed in the field as wet weights of pods. In 1998 the yield was only assessed from the single unsampled row in each whole plot. Because of difficulties to separate the sampled and unsampled rows after the plants had been dug and turned, the yield in 1999 was assessed from both rows within each whole plot.

Soil samples were collected and analyzed for the microsclerotia of *Cylindrocladium parasiticum* as described in the Materials and Methods section of Chapter 5. Microsclerotia were recovered from throughout the field.

Whole Plot Treatments

The field tests were planted using a split-plot experimental design. Each whole plot consisted of two rows 15.2 m in length and 0.92 m apart. Whole plot treatments were replicated four times in the field. The whole plot treatments were:

1. Chlorothalonil (tetrachloroisophthalonitrile, Bravo Ultrex® 82.5 WDG) applied biweekly at a rate of 1.6 kg ha^{-1} (1.4 lb $acre^{-1}$) beginning 6 weeks after planting.
2. A tank mixture of benomyl (methyl 1-(butylcarbamoyl)-benzimidazol-2-ylcarbamate, Benlate® 50 WP) at a rate of 0.57 kg ha^{-1} (1/2 lb) and chlorothalonil (1.6 kg ha^{-1}) applied at 6, 8, 10, and 12 weeks after planting.
3. A tank mixture of tebuconazole (H-1,2,4-triazole-1-ethanol α-[2-(4-chlorophenyl)-ethyl]-α-(1,1-dimethylethyl), Folicur® 3.6 F) applied at a rate of 0.53 L ha^{-1} (7.2 fl. oz./ acre) and chlorothalonil (1.6 kg ha^{-1}) applied at 6, 8, 10, and 12 weeks after planting.
4. A tank mixture of flutolanil (3'-isopropoxy-2-(trifluoromethyl) benzanilide, Moncut® 50 WP) and chlorothalonil (1.6 kg ha^{-1}) applied at 8 and 12 weeks after planting.

All fungicides were applied using a CO_2 backpack sprayer with a pressure of 207 kPa (30 PSI) and a spray volume of 264 L ha^{-1} (25 gal $acre^{-1}$). Two flat-fan nozzles were positioned 91 cm apart at the end of the spray boom. Chlorothalonil alone was applied 6 and 8 weeks after planting to those plots treated with flutolanil and 14 weeks after planting to all plots.

Subplot Treatments

Subplot treatments were differential times of sampling of the plants. Subplots were 1.52 m in length and two rows wide. Ten subplots were

randomized within each whole plot. Eight subplots were sequentially sampled on a biweekly basis beginning 2 weeks after planting. Destructive sampling was done in a single row based upon position within the subplot and without regard to the health of the plants. The plants were sampled at intervals of 30.5 cm within each subplot.

Plants were not collected from the second row within each whole plot. On each sampling date, disease severity that resulted from soilborne disease was assessed for each whole plot by the length of wilted row. In 1998 the yield from each whole plot was determined only from this row. In 1999, the yield was obtained from both the sampled and the intact row.

Sampling

On each sampling date, five plants were destructively sampled from the appropriate subplot. The plants were dug from the soil to ensure that a substantial portion of the roots, pegs, and pods were recovered. Excess foliage was removed from each sample but the foliage around the crown was left intact. The plants were placed in plastic bags marked for treatments and replicates. The bags were placed immediately in ice coolers. Upon return to the laboratory the samples were refrigerated until they could be processed. The samples were normally processed within 3 days after they were removed from the field.

Processing

The plants were processed as described in the materials and methods of Chapter 3.

Data Analysis

The yields from each treatment were analyzed by analysis of variance and Duncan's multiple range test. The area under the disease progress curve was calculated from the severities noted on each day of sampling. The epidemic rate (r) was based upon the monomolecular model for monocyclic pathosystems (179). To calculate the epidemic rate, disease severity measured in terms of the length of wilted row within each whole plot was transformed according to the equation

$$y = \ln(\text{total row length}/(\text{total row length} - \text{length of wilted row})).$$

The transformed values were then plotted against time (days) and the epidemic rate was calculated as the slope of the line fitted to the data points. Although a slight amount of disease developed early in the season during 1998, the most significant amount of wilt during both seasons was observed during the second half of the growing season. The epidemic rates were calculated from data collected during these later periods. The AUDPC values and the epidemic rates from each whole plot were evaluated by analysis of variance and Duncan's multiple range test.

The incidences of the 13 fungi assessed in this study were analyzed using both simple correspondence analysis and analysis of variance. Simple correspondence analysis was used to observe differences in the incidence of these fungi and the time or growth stage at which sampling occurred, the part of the plant from which the fungi were isolated, and the health ratings assigned to each plant prior to surface sterilization and sectioning. Closely associated

groups were encircled on the plots generated by correspondence analysis to facilitate interpretation. Analysis of variance was used to determine if there were significant differences in the incidence of these fungi among the four fungicide treatments at each sampling date. The means were separated using the method of least significant differences.

Assessment of the Microclimate

The development of the foliar canopy was monitored by a measure of the height and width in each whole plot on the sampling dates. The microclimate within the developing foliar canopy and within the pegging zone was measured in 1999 using Cricket-H temperature and relative humidity recorders and Cricket-T temperature recorders (Avatel, Inc., Ft. Bragg, CA) to measure soil temperature, air temperature, and relative humidity. One Cricket-H and one Cricket-T were placed in a plot treated with flutolanil (the most effective treatment from 1998) and a second set was placed in a plot treated with benomyl (the worst treatment in 1998). The data loggers were placed in the field on the third sampling date and remained in the field until the final sampling date. The data logger that collected soil temperatures was placed in the pegging zone 5 cm below the soil surface in close proximity to a young plant. The data logger used to measure relative humidity and air temperature was enclosed in a thermal shield to prevent exposure to direct sunlight, and then placed within the row of peanuts. The detector was eventually completely enclosed by the foliar canopy. The development of the canopy around the thermal shields in Jay was similar to that pictured in Figure 5-4. The objective of the detectors was to associate

changes in temperature and relative humidity within the soil and canopy with increasing isolation of important fungi, such as *C. parasiticum* and *S. rolfsii*.

Results

Sampling dates and the growth stages of the plants collected at each date were comparable between 1998 and 1999 (Table 6-1). Samples were collected on a biweekly basis, though a scheduling conflict in 1999 postponed the fifth sampling date by 1 week. Fungicide treatments did not affect the growth stages of the peanut plants collected at each sampling date (Table 6-1). In 1998, microsclerotia of *C. parasiticum* were recovered from 38 of 40 plots that were sampled at the time of planting. The number of microsclerotia in the soil samples varied between 0.0 and 15 per gram of soil. In 1999, microsclerotia were recovered from only two of 16 plots. The number of microsclerotia in the samples varied from 0.0 to 1.5 per gram of soil.

Yield and Disease Severity

The largest yields per whole plot in both seasons were from plots that received flutolanil and tebuconazole treatments (Table 6-2). In 1999 there was no significant difference between the tebuconazole, benomyl, and control treatments. Also, there was no significant difference between the flutolanil and tebuconazole treatments.

The areas under the disease progress curve and the epidemic rates calculated for the flutolanil and the tebuconazole treatments were lower than those calculated for the control and benomyl treatments in 1998 (Table 6-2). In 1999, the AUDPC value and the epidemic rate calculated for the flutolanil

Table 6-1. Sampling information from fungicide trials on peanuts, Santa Rosa County, Florida.

Event	Fungicide treatment	1998 'ViruGard' Date	Days after planting	Median growth stage[x]	1999 'Georgia Green' Date	Days after planting	Median growth stage[x]
Planting		5 May			1 May		
Sample 1		18 May	13		13 May	12	
	control			V3			V2
	tebuconazole			V2			V2
	benomyl			V2			V1-V2
	flutolanil			V2-V3			V2
Sample 2		2 Jun	28		26 May	25	
	control			V5			V5
	tebuconazole			V4-V5			V5
	benomyl			V5			V5
	flutolanil			V5			V5
Sample 3		16 Jun	42		15 Jun	45	
	control	*[y]		R2	*		R2
	tebuconazole	**[z]		R2	**		R2
	benomyl	**		R2	**		R2
	flutolanil	*		R2	*		R2
Sample 4		30 Jun	56		30 Jun	59	
	control	*		R3	*		R4
	tebuconazole	**		R3	**		R4-R5
	benomyl	**		R3	**		R4
	flutolanil	**		R3	**		R4
Sample 5		13 Jul	70		21 Jul	81	
	control	*		R5-R6	*		R5
	tebuconazole	**		R5	**		R5
	benomyl	**		R6	**		R5
	flutolanil	*		R5	*		R5
Sample 6		27 Jul	84		3 Aug	94	
	control	*		R6	*		R6
	tebuconazole	**		R6	**		R6
	benomyl	**		R6	**		R6
	flutolanil	**		R6	**		R6
Sample 7		11 Aug	98		18 Aug	109	
	control	*		R8	*		R8
	tebuconazole	*		R8	*		R8
	benomyl	*		R8	*		R8
	flutolanil	*		R8	*		R8
Sample 8		21 Aug	109		2 Sept	124	
	control	*		R8	*		R8
	tebuconazole	*		R8	*		R8
	benomyl	*		R8	*		R8
	flutolanil	*		R8	*		R8
Harvest		29 Aug	117		8 Sept	130	

[x] A summary of the growth stages of the peanut plant is presented in Table 3-5; briefly, V1-V6 = vegetative stages in increasing maturity and R = reproductive stages with R1 = beginning bloom, R2 = beginning peg, R3 = beginning pod formation, R4 = full pod formation, R5 = beginning seed formation, R6 = the full seed stage of development, R7 = beginning maturity, and R8 = harvest maturity of the pods.

[y] *= application of chlorothalonil.

[z] **= application of chlorothalonil and tebuconazole, benomyl, or flutolanil.

Table 6-2. Yield and disease severity during 1998 and 1999 associated with four fungicide programs on peanuts in Santa Rosa County, Florida.

	Yield[w] (kg per whole plot)		AUDPC[x]		Epidemic rate (r)[y]		R^2 value	
Treatment	1998	1999	1998	1999	1998	1999	1998	1999
control	6.8 B[z]	9.1 B[z]	365 A	334 A	0.098 B	0.020 A	0.92	0.96
tebuconazole	7.6 A	9.9 AB	77 B	251 AB	0.022 C	0.012 AB	0.81	0.98
benomyl	6.2 B	8.4 B	459 A	415 A	0.167 A	0.018 A	0.86	0.95
flutolanil	8.2 A	11.8 A	87 B	125 B	0.015 C	0.007 B	0.75	1.0

[v] Results from 1998 were based upon the cultivar ViruGard; results from 1999 were based on Georgia Green.

[w] In 1998 peanuts were only harvested from the row in each whole plot that was not sampled. In 1999, peanuts were harvested from both the sampled and the unsampled rows.

[x] "Area under the disease progress curve" was used as a measure of disease severity.

[y] The apparent infection rate was determined with the monomolecular model, [ln(1/(1-y))], to transform disease severity measure in the length of wilted row at each sampling date.

[z] The values from 1998 followed by different letters were significantly different at the $\alpha = 0.05$ level. The values from 1999 followed by different letters were significantly different at the $\alpha = 0.1$ level.

treatment were lower than those calculated for either the control or the benomyl treatment. The values of the epidemic rate and the AUDPC calculated for the tebuconazole treatment were not different from any of the other treatments.

Canopy Development

The size of the canopy began to increase substantially by 40 days after planting and had completely closed by 80 days after planting (Figure 6-1). In this study, a completely closed canopy was defined as one in which the vegetative growth of one row of peanuts overlapped the foliage in neighboring rows. Near the end of the season, the size of the canopy decreased because of a reduction in height. The reduction in the canopy was most noticeable in 1999 because of severe wilt from drought.

The temperature within the canopy and in the pegging zone began to decrease approximately 65 and 70 days after planting, but increased again between 80 and 90 days after planting (Figure 6-2). The relative humidity was high throughout the measured period except prior to 50 days and later than 100 days after planting (Figure 6-3). The changes in temperature and relative humidity at the end of the season were related to general wilt of the crop and the collapse of the canopy (Figure 6-1). The recorder that collected the temperature and relative humidity data from within the canopy was contained in a thermal shield to protect it from direct solar radiation. Therefore, the data were related to conditions in the canopy, but were also influenced by the protective shield. For example, any condensation on the probe that measured relative humidity may have taken longer to evaporate in the morning than if the recorder had not been

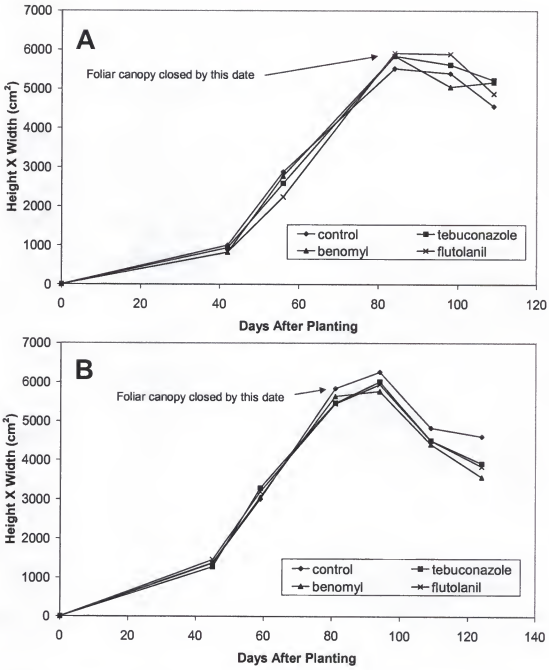


Figure 6-1. Development of the foliar canopies associated with four different fungicide programs in two commercial fields of peanut in Santa Rosa County, Florida in 1998 (A) and 1999 (B). The development of the canopy was measured as the product of the height and the width of the canopy measured at a single representative point in each subplot sampled on a given date. The points on the graphs represent the mean value for each treatment on each date.

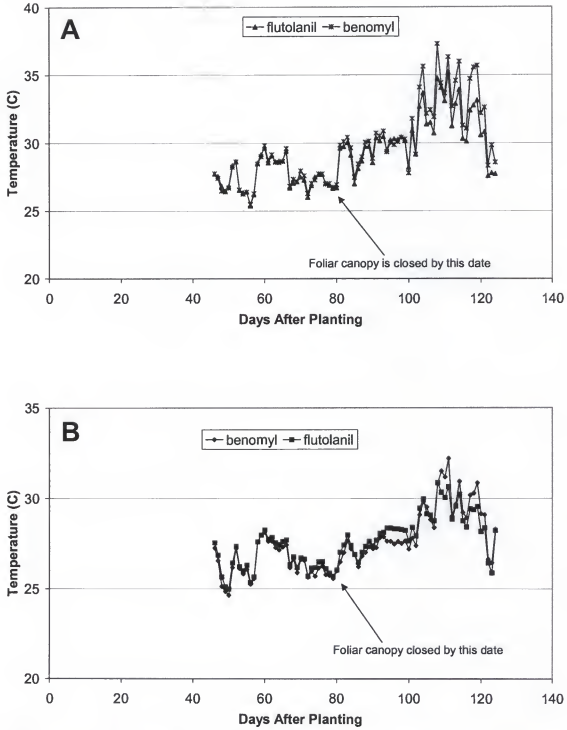


Figure 6-2. Changes in the peanut canopy (A) and soil (B) temperature associated with two fungicide programs in a commercial field in Santa Rosa County during 1999. Each point represents the average temperature between 9:00 AM and 6:00 PM measured hourly.

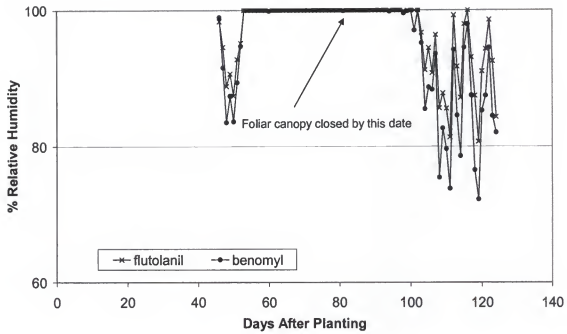


Figure 6-3. The changes in % relative humidity within monitoring stations placed in the developing canopies of peanut that received different fungicide programs in a commercial field in Santa Rosa County. Each point on this graph represents the value of the % relative humidity within a thermal shield on that day-after-planting averaged over the measurements taken hourly between 9:00 AM and 6:00 PM.

shielded. However, if the data recorder had not been shielded, it would have been excessively heated by direct solar radiation. Each point on the graphs in Figures 6-2 and 6-3 represent the mean value for data collected hourly between 9:00 AM and 6:00 PM, which was the warmest period of a day.

Correspondence Analysis

In 1998, based on correspondence analysis, the incidences of the soilborne fungi formed two general groups in association with the time of sampling, while in 1999 there were four groups (Figures 6-4 and 6-5). In 1999, some fungi were associated with the earliest sampling dates. In both years, the sampling dates, an indication of the growth stages of the host, were primarily spread along the horizontal axis, though T1 was separated by a vertical component as well. Sampling dates were generally clustered as T1, T2+T3, T4, T5 or T5+T6+T7, and T6+T7+T8 or T8. Regardless of the exact clustering of dates, the earlier growth stages were distinct and separate from the later reproductive stages. The largest clusters of fungal incidence in both seasons were centered around the origin. Fungi that were clustered around the origin in 1998 and 1999 included *A. niger* (2A, B, C, D), *Fusarium* spp. (4A, B, C, D), *M. phaseolina*, (6A, B, C, D) and *N. vasinfecta* (7A, B, C, D). In 1998, the incidences of *A. flavus* (1A, B, C, D) and *Rhizopus* spp. (11A, B, C, D) were also clustered about the origin. However, in 1999, *A. flavus* from the control plot (1A), *R. solani* from the control plots and those plots that received tebuconazole (10 A, B), and *Rhizopus* spp. from the control plot and the plots that received benomyl (11 A, C) were more closely associated with earlier growth stages (T1, T2). A

Figure 6-4. Simple correspondence analysis from 1998 to establish the relationship between the time of sampling and the incidence of specific fungi isolated from four fungicide treatments. The variables T1 through T8 represent the eight sequential sampling dates during the field season. The letters A, B, C, and D represent the fungicide treatments applied to the peanut plants from which the isolations were made. The control is represented by A, the tebuconazole treatment by B, the benomyl treatment by C, and the flutolanil treatment by D. The fungi are represented as follows *Aspergillus flavus* (1), *Aspergillus niger* (2), *Cylindrocladium parasiticum* (3), *Fusarium* spp. (4), *Lasiodiplodia theobromae* (5), *Macrophomina phaseolina* (6), *Neocosmospora vasinfecta* (7), *Phomopsis* sp. (8), *Pythium* spp. (9), *Rhizoctonia solani* (10), *Rhizopus* spp. (11), *Sclerotium rolfsii* (12), and *Trichoderma* spp. (13). Units on the horizontal and vertical axes were not defined when the results obtained by correspondence analysis were plotted.

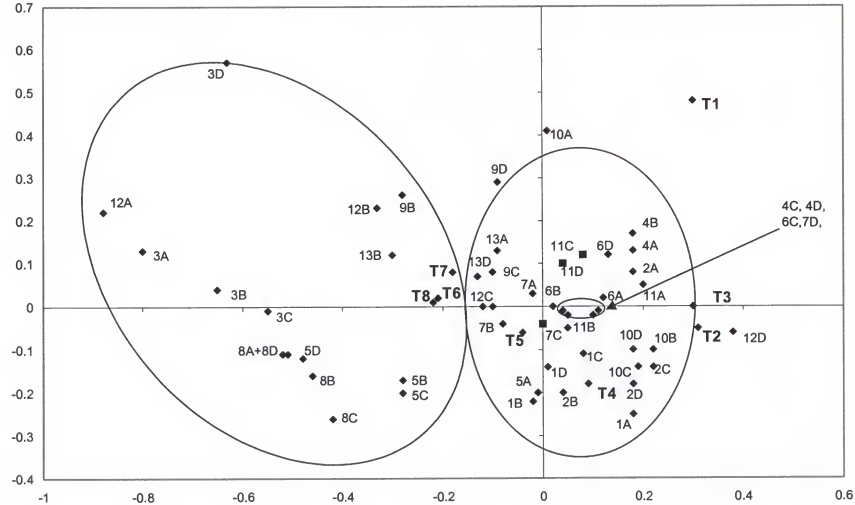
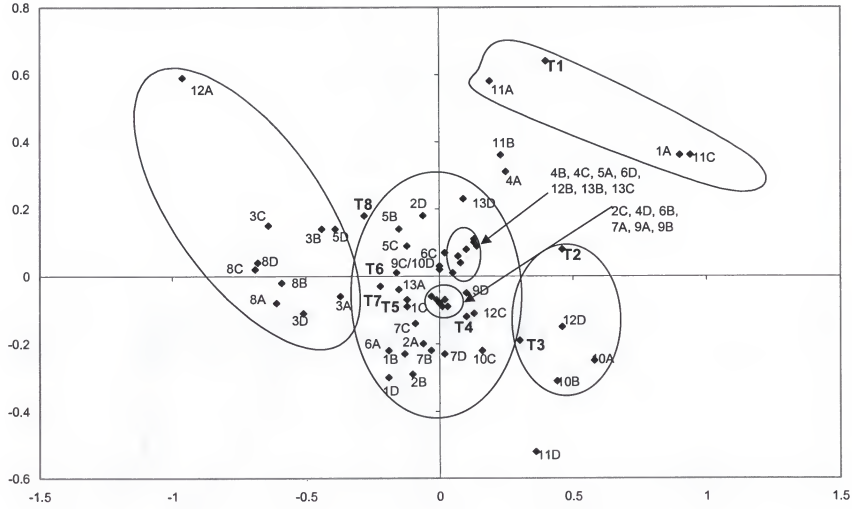

0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
3D
12A
3A
3B
3C
8A+8D
5D
8B
8C
12B
9B
13B
5B
5C
T7
T8
T6
13A
13D
9C
12C
7B
T5
9D
10A
T1
4C, 4D,
6C,7D,
4B
11C
6D
4A
2A
11D
7A
6B
6A
11A
T3
7C
11B
10D
10B
T2
12D
1C
1D
10C
2C
5A
1B
2B
T4
2D
1A

Figure 6-5. Simple correspondence analysis from 1999 to establish the relationship between the time of sampling and the incidence of specific fungi isolated from four fungicide treatments. The variables T1 through T8 represent the eight sequential sampling dates during the field season. The letters A, B, C, and D represent the fungicide treatments applied to the peanut plants from which the isolations were made. The control is represented by A, the tebuconazole treatment by B, the benomyl treatment by C, and the flutolanil treatment by D. The fungi are represented as follows: *Aspergillus flavus* (1), *Aspergillus niger* (2), *Cylindrocladium parasiticum* (3), *Fusarium* spp. (4), *Lasiodiplodia theobromae* (5), *Macrophomina phaseolina* (6), *Neocosmospora vasinfecta* (7), *Phomopsis* sp. (8), *Pythium* spp. (9), *Rhizoctonia solani* (10), *Rhizopus* spp. (11), *Sclerotium rolfsii* (12), and *Trichoderma* spp. (13). Units on the horizontal and vertical axes were not defined when the results obtained by correspondence analysis were plotted.


0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-1.5
-1
-0.5
0
0.5
1
1.5
T1
T2
T3
T4
T5
T6
T7
T8
12A
11A
11B
1A
11C
4A
4B, 4C, 5A, 6D,
12B, 13B, 13C
2C, 4D, 6B,
7A, 9A, 9B
3C
3B
5D
8C
8D
8B
8A
3D
3A
5B
2D
13D
5C
6C
9C/10D
13A
9B
1C
12C
7C
12D
6A
2A
1B
7B
7D
10C
10A
10B
2B
1D
11D

late season cluster of more loosely arranged points occurred in 1998 and in 1999. These clusters were clearly linked with growth stages at the end of the season. Fungi that were associated with the end of the season included *Phomopsis* sp. (8A, B, C, D) and *C. parasiticum* (3A, B, C, D). In 1998, *L. theobromae* from those plots that received benomyl, tebuconazole, or flutolanil (5B, C, D) were associated with the later growth stages and *L. theobromae* from the control (5A) was positioned closer to the origin. In 1999, *L. theobromae* from the plots treated with flutolanil, benomyl, and tebuconazole were also positioned apart from *L. theobromae* from control plots. However, *L. theobromae* from the plots treated with tebuconazole and benomyl (5B, C) were positioned more closely to the origin than in 1998. In 1998 and 1999, the incidence of *S. rolfsii* from the control plots was associated with the end of the season while the incidence of *S. rolfsii* from those plots treated with flutolanil was positioned very differently and was positioned between the late vegetative and early reproductive stages of T2 and T3.

In both 1998 and 1999, the incidences of some fungi were closely associated with the hypocotyls (P2), pegs (P4), roots (P3), or roots and pods (P3+P5) (Figures 6-6 and 6-7). *Rhizopus* spp. (11A, B, C, D) was more closely associated with the hypocotyls (P2) than any other fungus. However, in 1998, the incidences of *A. flavus* and *L. theobromae* from the control plots (1A, 5A) and *S. rolfsii* from plots treated with tebuconazole were also disproportionately associated with the hypocotyls. In 1998 and 1999, the incidence of *Phomopsis* sp. (8A, B, C, D) was closely associated with the pegs (P4) as was the incidence

Figure 6-6. Simple correspondence analysis from 1998 to establish the relationship between the parts of the plant and the incidence of specific fungi isolated from four fungicide treatments. The variables P1 through P5 represent the five parts of the plant from which fungi were isolated. The total plant is represented by P1, hypocotyls by P2, roots by P3, pegs by P4, and the pods by P5. The letters A, B, C, and D represent the fungicide treatments applied to the peanut plants from which the isolations were made. The control is represented by A, the tebuconazole treatment by B, the benomyl treatment by C, and the flutolanil treatment by D. The fungi are represented as follows: *Aspergillus flavus* (1), *Aspergillus niger* (2), *Cylindrocladium parasiticum* (3), *Fusarium* spp. (4), *Lasiodiplodia theobromae* (5), *Macrophomina phaseolina* (6), *Neocosmospora vasinfecta* (7), *Phomopsis* sp. (8), *Pythium* spp. (9), *Rhizoctonia solani* (10), *Rhizopus* spp. (11), *Sclerotium rolfsii* (12), and *Trichoderma* spp. (13). Units on the horizontal and vertical axes were not defined when the results obtained by correspondence analysis were plotted.

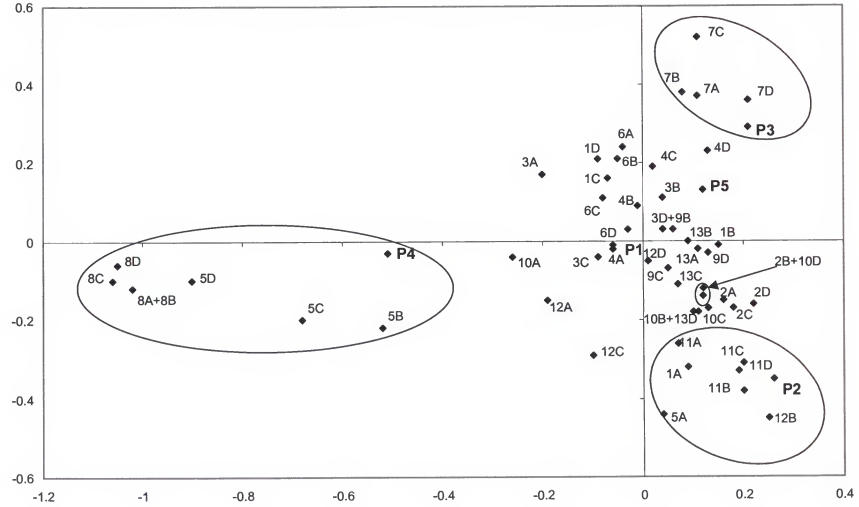
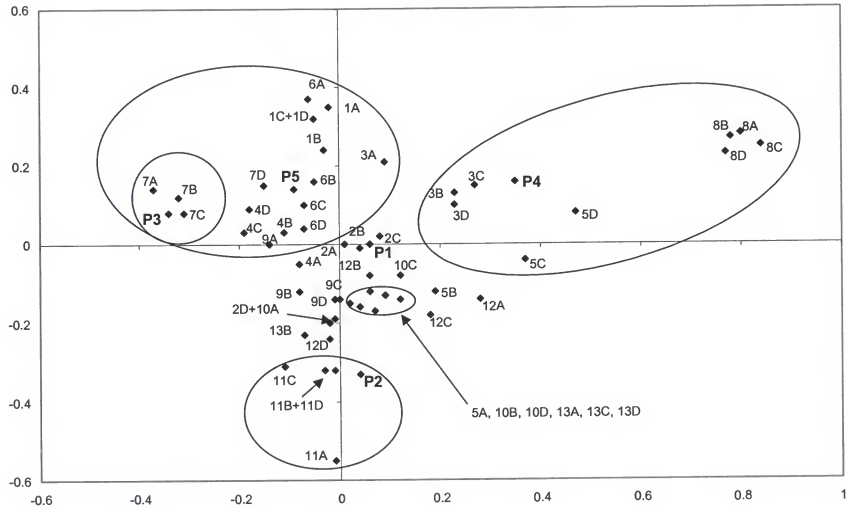

0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-1.2
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
7C
7B
7A
7D
P3
6A
1D
6B
4C
4D
3A
1C
3B
P5
4B
6C
3D+9B
6D
13B
1B
P4
P1
12D
13A
9D
8D
8C
5D
10A
3C
4A
9C
13C
2B+10D
2A
2D
8A+8B
5C
5B
12A
10B+13D
10C
2C
11A
12C
11C
11D
1A
11B
P2
5A
12B

Figure 6-7. Simple correspondence analysis from 1999 to establish the relationship between the parts of the plant and the incidence of specific fungi isolated from four fungicide treatments. The variables P1 through P5 represent the five parts of the plant from which fungi were isolated. The total plant is represented by P1, hypocotyls by P2, roots by P3, pegs by P4, and the pods by P5. The letters A, B, C, and D represent the fungicide treatments applied to the peanut plants from which the isolations were made. The control is represented by A, the tebuconazole treatment by B, the benomyl treatment by C, and the flutolanil treatment by D. The fungi are represented as follows: *Aspergillus flavus* (1), *Aspergillus niger* (2), *Cylindrocladium parasiticum* (3), *Fusarium* spp. (4), *Lasiodiplodia theobromae* (5), *Macrophomina phaseolina* (6), *Neocosmospora vasinfecta* (7), *Phomopsis* sp. (8), *Pythium* spp. (9), *Rhizoctonia solani* (10), *Rhizopus* spp. (11), *Sclerotium rolfsii* (12), and *Trichoderma* spp. (13). Units on the horizontal and vertical axes were not defined when the results obtained by correspondence analysis were plotted.


0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
6A
1A
1C+1D
1B
3A
7A
7B
7C
7D
P5
6B
6C
4D
P3
4C
4B
6D
9A
2B
2C
2A
P1
4A
12B
10C
9C
9B
9D
2D+10A
13B
12D
5B
12A
12C
8B
8A
8C
8D
3C
P4
3B
3D
5D
5C
11C
P2
11B+11D
11A
5A, 10B, 10D, 13A, 13C, 13D

of *L. theobromae* from all treatments except for the control (5B, C, D). *Neocosmospora vasinfecta* was closely associated with the roots (P3) for all treatments (7A, B, C, D). There was a large group generally associated with the whole plant (P1) that sometimes difficult to separate from those associated with the pods (P5). During each season, the point that represented the total incidence of a fungus in the plant was positioned close to the origin. Fungi that were positioned near the origin included *A. niger* (2A, B, C, D), *Fusarium* spp. (4A, B, C, D), *R. solani* (10A, B, C, D), *Pythium* spp. (9A, B, C, D), and *Trichoderma* spp. (13A, B, C, D). *A. flavus*, *M. phaseolina*, and *C. parasiticum* could be placed with the total plant (P1) and the pods (P5) in 1998. In 1999, *C. parasiticum* was more closely associated with the pegs of the plant.

In 1998 and 1999, the incidences of *S. rolfsii* (12A, C) and *C. parasiticum* (3A, C) from the control and those plots treated with benomyl were associated with severely diseased plants (R4) (Figures 6-8 and 6-9). In both seasons, the incidences of the fungi from a single fungicide treatment (A, B, C, or D) were generally grouped together either independently or in combination with one other treatment. These groups are circled on each figure. Fungi from those plots treated with benomyl (C) were generally associated with the most diseased plants while those from plots that received flutolanil (D) were associated with the healthiest plants. In 1998, fungi from plots treated with tebuconazole were associated with fungi from those plots treated with flutolanil; however, in 1999, the fungi from the tebuconazole plots were most closely associated with fungi

Figure 6-8. Simple correspondence analysis from 1998 establishing the relationship between the health rating given to each sampled plant and the incidence of specific fungi isolated from four fungicide treatments. The variables R1 through R5 represent the five health ratings given to the plant from which fungi were isolated. A symptomless plant is represented by R1. Plants with discoloration or restricted lesions are represented by R2. The plants with expanding lesions and slight wilt are represented by R3. The plants with more substantial wilt and some necrotic tissue are represented by R4. The plants with severe wilt and necrosis to the point of death are represented by R5. The letters A, B, C, and D represent the fungicide treatments applied to the peanut plants from which the isolations were made. The control is represented by A, the tebuconazole treatment by B, the benomyl treatment by C, and the flutolanil treatment by D. The fungi are represented as follows: *Aspergillus flavus* (1), *Aspergillus niger* (2), *Cylindrocladium parasiticum* (3), *Fusarium* spp. (4), *Lasiodiplodia theobromae* (5), *Macrophomina phaseolina* (6), *Neocosmospora vasinfecta* (7), *Phomopsis* sp. (8), *Pythium* spp. (9), *Rhizoctonia solani* (10), *Rhizopus* spp. (11), *Sclerotium rolfsii* (12), and *Trichoderma* spp. (13). Units on the horizontal and vertical axes were not defined when the results obtained by correspondence analysis were plotted.

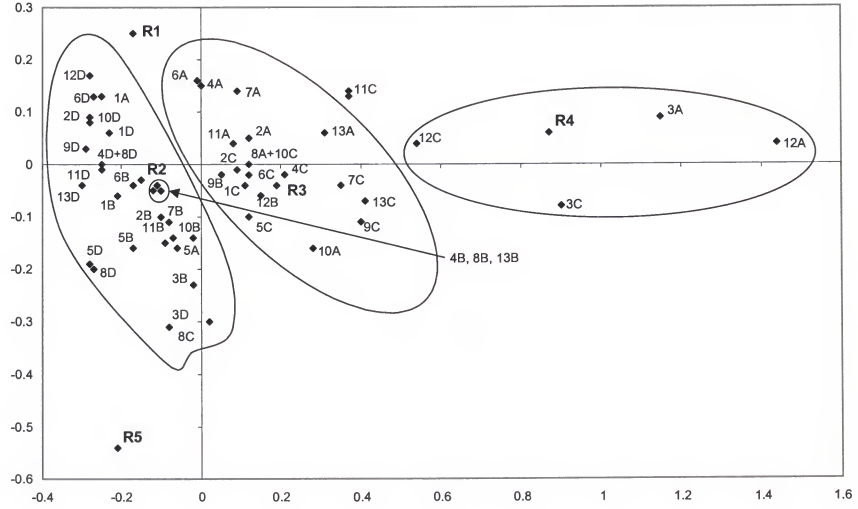
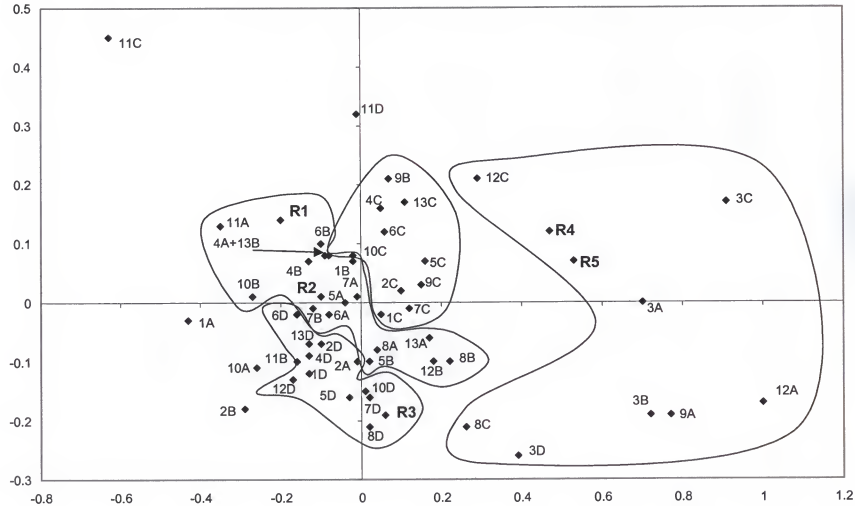

R1
R2
R3
R4
R5
12D
6D
1A
2D
10D
1D
9D
4D+8D
11D
6B
13D
1B
2B
7B
11B
10B
5B
5A
5D
8D
3B
3D
8C
6A
4A
7A
11C
11A
2A
13A
2C
8A+10C
9B
1C
6C
4C
12B
7C
13C
9C
5C
10A
4B, 8B, 13B
12C
3A
12A
3C
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6

Figure 6-9. Simple correspondence analysis from 1999 establishing the relationship between the health rating given to each sampled plant and the incidence of specific fungi isolated from four fungicide treatments. The variables R1 through R5 represent the five health ratings given to the plant from which fungi were isolated. A symptomless plant is represented by R1. Plants with discoloration or restricted lesions are represented by R2. The plants with expanding lesions and slight wilt are represented by R3. The plants with more substantial wilt and some necrotic tissue are represented by R4. The plants with severe wilt and necrosis to the point of death are represented by R5. The letters A, B, C, and D represent the fungicide treatments applied to the peanut plants from which the isolations were made. The control is represented by A, the tebuconazole treatment by B, the benomyl treatment by C, and the flutolanil treatment by D. The fungi are represented as follows: *Aspergillus flavus* (1), *Aspergillus niger* (2), *Cylindrocladium parasiticum* (3), *Fusarium* spp. (4), *Lasiodiplodia theobromae* (5), *Macrophomina phaseolina* (6), *Neocosmospora vasinfecta* (7), *Phomopsis* sp. (8), *Pythium* spp. (9), *Rhizoctonia solani* (10), *Rhizopus* spp. (11), *Sclerotium rolfsii* (12), and *Trichoderma* spp. (13). Units on the horizontal and vertical axes were not defined when the results obtained by correspondence analysis were plotted.


0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
11C
11D
9B
12C
3C
4C
13C
R1
11A
6B
6C
R4
4A+13B
10C
5C
R5
4B
1B
7A
2C
9C
10B
R2
5A
3A
6D
7B
6A
1C
7C
1A
13D
8A
13A
2D
11B
4D
5B
8B
10A
1D
2A
12B
12A
12D
5D
10D
3B
9A
2B
7D
R3
8C
8D
3D

from the control. This was interpreted as a shift from healthier plants in 1998 to less healthy plants in 1999 for plots that received tebuconazole.

Analysis of Variance

The mean incidences of *A. flavus, A. niger, C. parasiticum, Fusarium* spp., *M. phaseolina*, *N. vasinfecta*, *Pythium* spp., *Rhizopus* spp., and *Trichoderma* spp. were not consistently different among plants sprayed with different fungicides (Figures 6-10 to 6-13, 6-15, 6-16, 6-18, 6-20, 6-22). There were significant differences among treatments for *L. theobromae*, *Phomopsis* spp., *R. solani*, and *S. rolfsii* (Figures 6-14, 6-17, 6-19, 6-21). In 1998, the incidence of *L. theobromae* was lower in plots treated with benomyl than in the control at 56, 74, and 80 days after planting (Figure 6-14). In 1998, plots treated with benomyl had a lower incidence of *Phomopsis* sp. than the control at 70 and 84 days after planting. In both 1998 and 1999, plots treated with tebuconazole tended to have a lower incidence of *R. solani* than did the control plots. In 1998, the incidence of *R. solani* was lower at 70, 84, and 98 days after planting. In 1999, the incidence of *R. solani* was lower in the plots sprayed with tebuconazole at 59 and 81 days after planting.

In 1998 and 1999, the incidence of *S. rolfsii* in plots treated with either flutolanil or tebuconazole tended to be lower than those treated with benomyl or in the control plots. In 1998, *S. rolfsii* was isolated from the control plots and the plots treated with benomyl at 70 days after planting, but was not isolated from the plots treated with tebuconazole or flutolanil until 84 days after planting. At 84 days after planting, the incidences of *S. rolfsii* in the control and in the plots

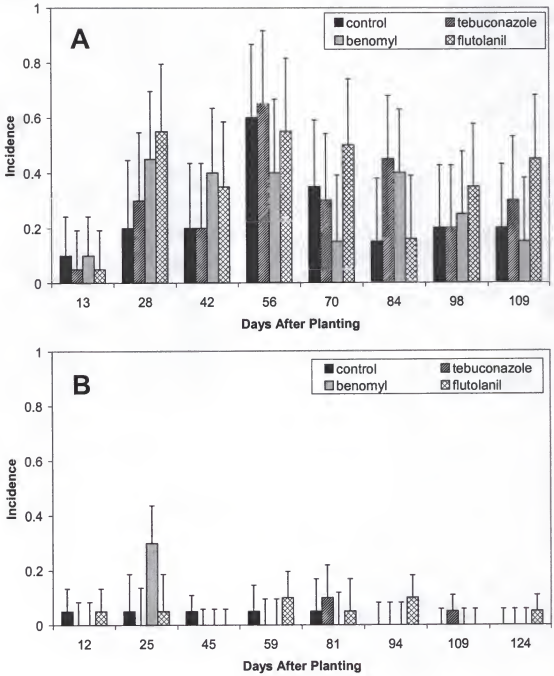


Figure 6-10. Incidence of *Aspergillus flavus* measured as the proportion of infected peanut plants sampled from plots sprayed with four different fungicides in Santa Rosa County, Florida, in 1998 (A) and 1999 (B). Mean incidence was calculated by analysis of variance; error bars represent the results of mean comparisons by least significant differences at the $\alpha = 0.1$ level. Error bars represent differences on a single date.

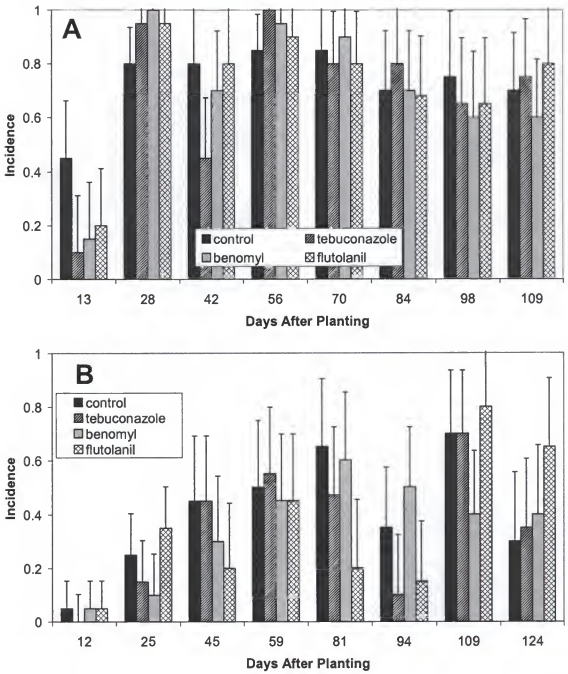


Figure 6-11. Incidence of *Aspergillus niger* measured as the proportion of infected peanut plants sampled from plots sprayed with four different fungicides in Santa Rosa County, Florida, in 1998 (A) and 1999 (B). Mean incidence was calculated by analysis of variance; error bars represent the results of mean comparisons by least significant differences at the $\alpha = 0.1$ level. Error bars represent differences on a single date.

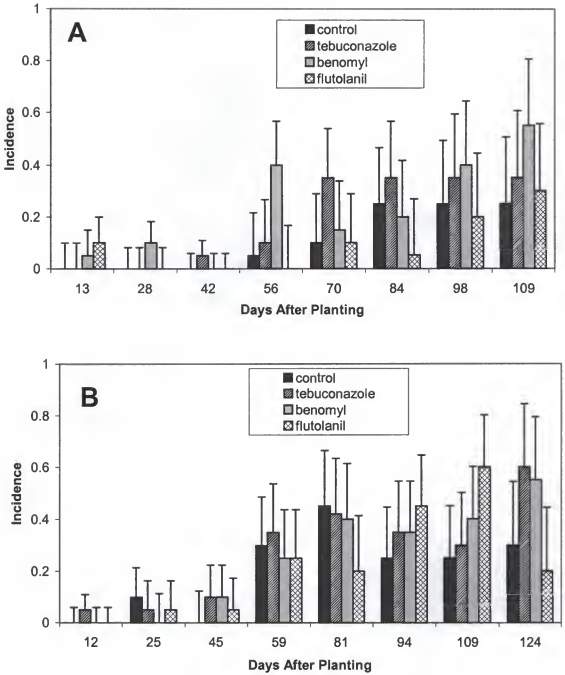


Figure 6-12. Incidence of *Cylindrocladium parasiticum* measured as the proportion of infected peanut plants sampled from plots sprayed with four different fungicides in Santa Rosa County, Florida, in 1998 (A) and 1999 (B). Mean incidence was calculated by analysis of variance; error bars represent the results of mean comparisons by least significant differences at the $\alpha = 0.1$ level. Error bars represent differences on a single date.

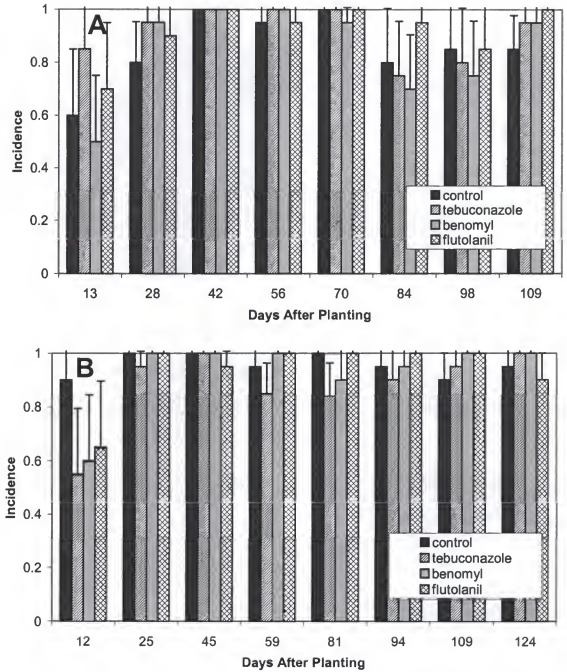


Figure 6-13. Incidence of *Fusarium* spp. measured as the proportion of infected peanut plants sampled from plots sprayed with four different fungicides in Santa Rosa County, Florida, in 1998 (A) and 1999 (B). Mean incidence was calculated by analysis of variance; error bars represent the results of mean comparisons by least significant differences at the $\alpha = 0.1$ level. Error bars represent differences on a single date.

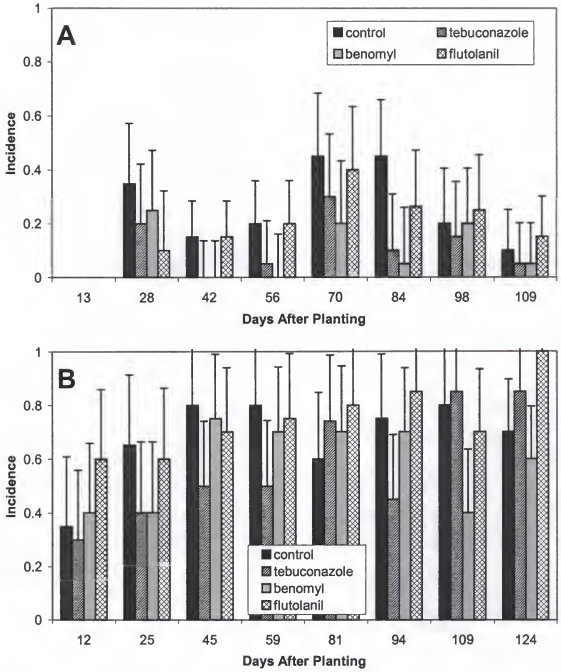


Figure 6-14. Incidence of *Lasiodiplodia theobromae* measured as the proportion of infected peanut plants sampled from plots sprayed with four different fungicides in Santa Rosa County, Florida, in 1998 (A) and 1999 (B). Mean incidence was calculated by analysis of variance; error bars represent the results of mean comparisons by least significant differences at the $\alpha = 0.1$ level. Error bars represent differences on a single date.

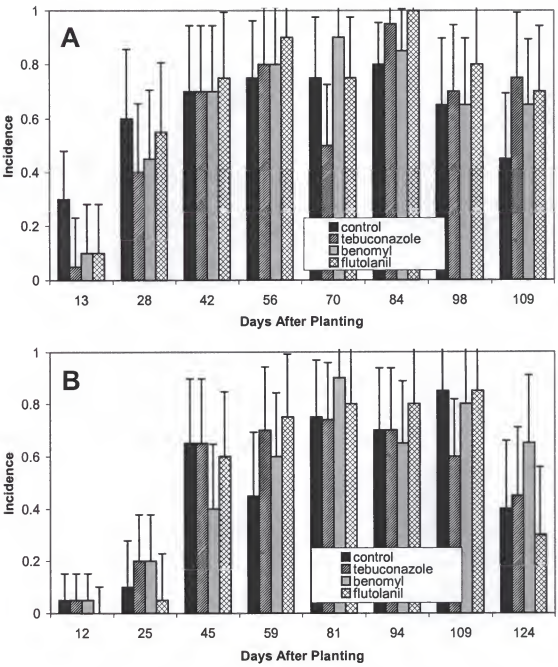


Figure 6-15. Incidence of *Macrophomina phaseolina* measured as the proportion of infected peanut plants sampled from plots sprayed with four different fungicides in Santa Rosa County, Florida, in 1998 (A) and 1999 (B). Mean incidence was calculated by analysis of variance; error bars represent the results of mean comparisons by least significant differences at the $\alpha = 0.1$ level. Error bars represent differences on a single date.

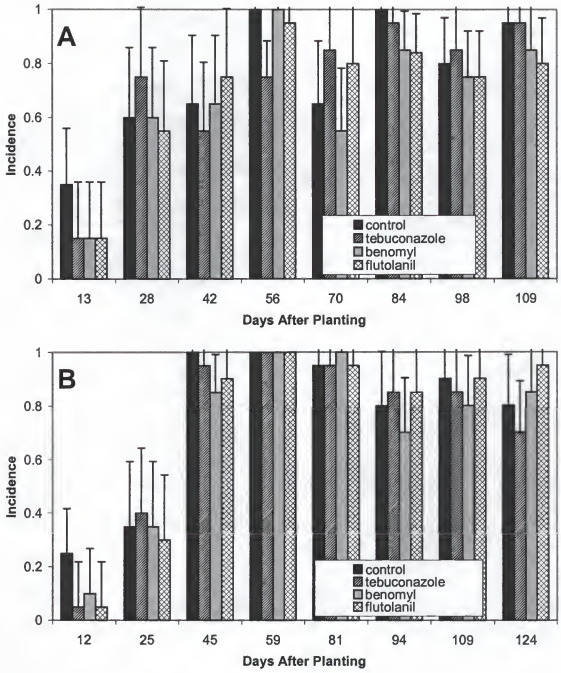


Figure 6-16. Incidence of *Neocosmospora vasinfecta* measured as the proportion of infected peanut plants sampled from plots sprayed with four different fungicides in Santa Rosa County, Florida, in 1998 (A) and 1999 (B). Mean incidence was calculated by analysis of variance; error bars represent the results of mean comparisons by least significant differences at the $\alpha = 0.1$ level. Error bars represent differences on a single date.

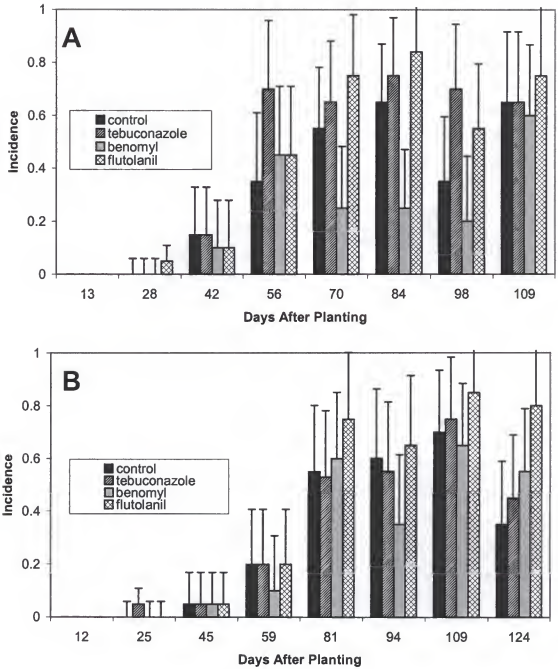


Figure 6-17. Incidence of *Phomopsis* sp. measured as the proportion of infected peanut plants sampled from plots sprayed with four different fungicides in Santa Rosa County, Florida, in 1998 (A) and 1999 (B). Mean incidence was calculated by analysis of variance; error bars represent the results of mean comparisons by least significant differences at the $\alpha = 0.1$ level. Error bars represent differences on a single date.

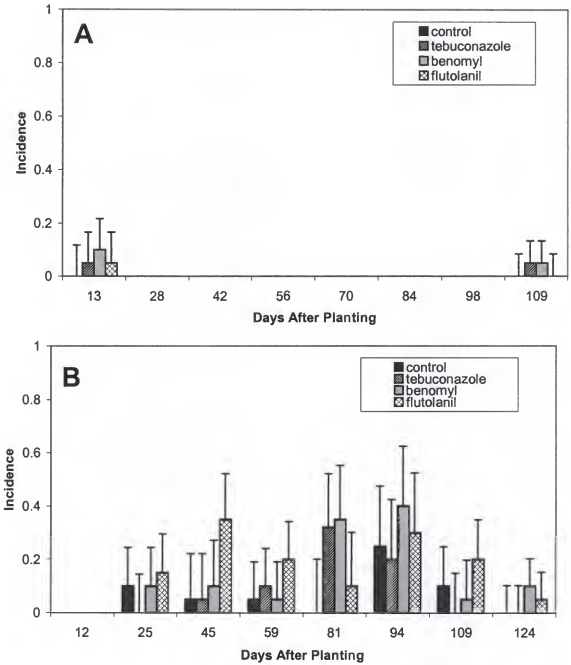


Figure 6-18. Incidence of *Pythium* spp. measured as the proportion of infected peanut plants sampled from plots sprayed with four different fungicides in Santa Rosa County, Florida, in 1998 (A) and 1999 (B). Mean incidence was calculated by analysis of variance; error bars represent the results of mean comparisons by least significant differences at the $\alpha = 0.1$ level. Error bars represent differences on a single date.

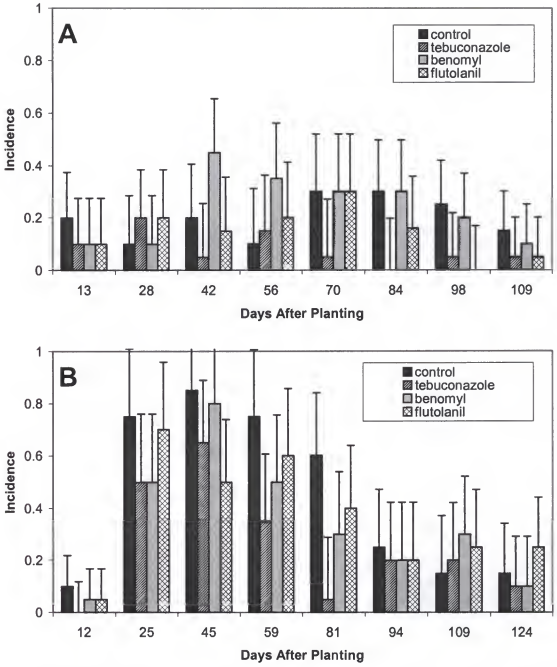


Figure 6-19. Incidence of *Rhizoctonia solani* measured as the proportion of infected peanut plants sampled from plots sprayed with four different fungicides in Santa Rosa County, Florida, in 1998 (A) and 1999 (B). Mean incidence was calculated by analysis of variance; error bars represent the results of mean comparisons by least significant differences at the $\alpha = 0.1$ level. Error bars represent differences on a single date.

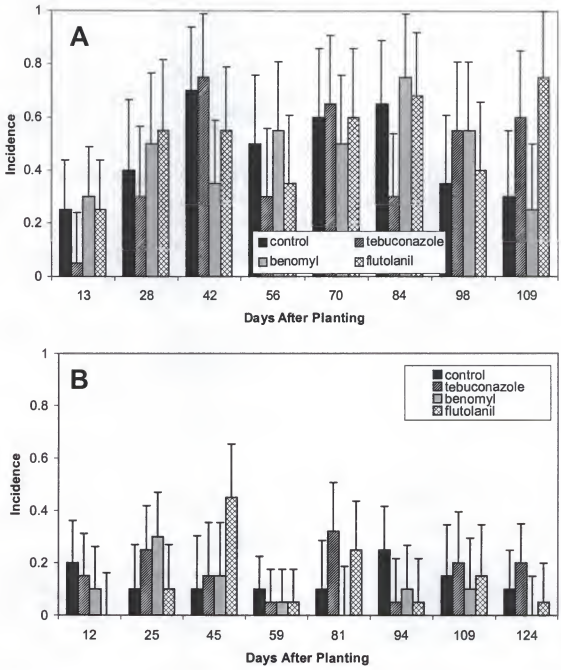


Figure 6-20. Incidence of *Rhizopus* spp. measured as the proportion of infected peanut plants sampled from plots sprayed with four different fungicides in Santa Rosa County, Florida, in 1998 (A) and 1999 (B). Mean incidence was calculated by analysis of variance; error bars represent the results of mean comparisons by least significant differences at the $\alpha = 0.1$ level. Error bars represent differences on a single date.

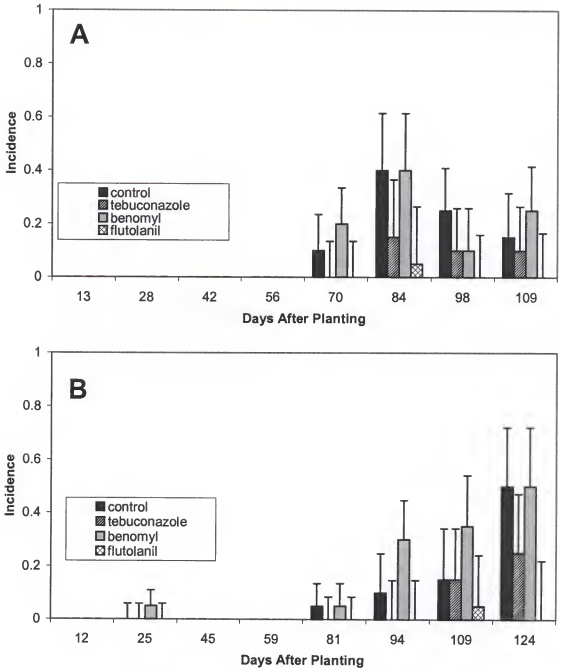


Figure 6-21. Incidence of *Sclerotium rolfsii* measured as the proportion of infected peanut plants sampled from plots sprayed with four different fungicides in Santa Rosa County, Florida, in 1998 (A) and 1999 (B). Mean incidence was calculated by analysis of variance; error bars represent the results of mean comparisons by least significant differences at the $\alpha = 0.1$ level. Error bars represent differences on a single date.

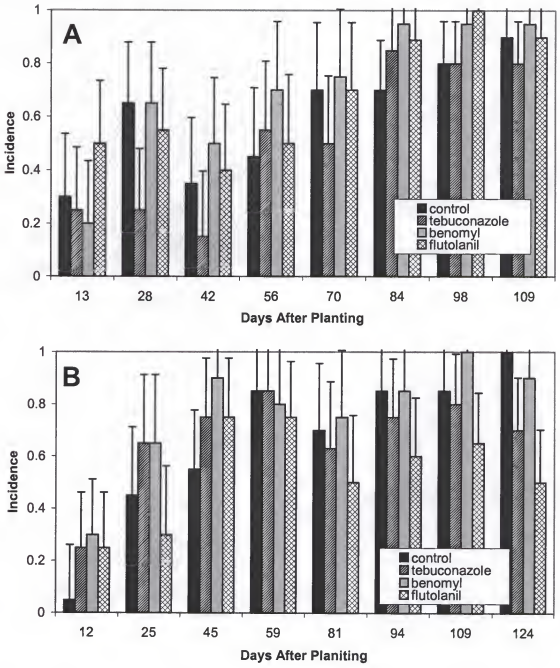


Figure 6-22. Incidence of *Trichoderma* spp measured as the proportion of infected peanut plants sampled from plots sprayed with four different fungicides in Santa Rosa County, Florida, in 1998 (A) and 1999 (B). Mean incidence was calculated by analysis of variance; error bars represent the results of mean comparisons by least significant differences at the $\alpha = 0.1$ level. Error bars represent differences on a single date.

treated with benomyl were significantly greater than in plots treated with flutolanil or tebuconazole. The incidence of *S. rolfsii* was also lower in plots treated with flutolanil at 98 days after planting. In 1999, *S. rolfsii* was isolated from the control at 81 and 94 days after planting and was first isolated from plots treated with tebuconazole and flutolanil at 109 days after planting. At 124 days after planting, there was a lower incidence of *S. rolfsii* in plots treated with tebuconazole and flutolanil than in the control. In 1999, the incidence of *S. rolfsii* was greater in the plots that received benomyl than in the control plots at 94 and 109 days after planting.

Discussion

In this study, the applications of four fungicides did not affect the development of the peanut plants. The growth stages of the plants in 1998 and 1999 were similar on sequential sampling dates despite differences in year, fields, and cultivar. Any changes in the incidences of soilborne fungi or the communities of fungi among treatments did not result from an interaction between the development of the host and the fungicides. The only difference between the two seasons occurred during the fourth sampling date. In 1998, the plants at the fourth sampling date were associated predominantly with the earliest pod-formation stage while in 1999 the plants had entered the earliest seed-formation stage.

Canopy Development

The traditional plant disease triangle is composed of the interactions between the host, the pathogen, and the environment. The importance of the

foliar canopy includes not only its role in photosynthesis, but also its affect on the microclimate near the soil surface. Coverage by the canopy may influence relative humidity and ambient temperature and thus optimize conditions for fungal growth and development. Stewart et al. (165) found that season-long averages for ambient temperature and humidity were higher within the foliar canopy than above it. Their results are confusing, as one would expect the shaded interior of the canopy to be cooler than that area exposed to direct sunlight. In a study of the relationships between temperatures within the foliar canopy, on the stems, and on the developing peanut pods, Sanders et al. (150) found that the mean temperature within the canopy of irrigated peanuts was nearly 7° C cooler than the temperature in drought-stressed peanuts.

The closure of the foliar canopy has been considered an important event that affects the temperature of the soil within the peanut row and the development of Cylindrocladium black rot (156). In a comparison of peanuts planted in raised beds and in flat rows, soil temperatures generally exceeded 28° C longer in the bedded rows after the canopy had closed and reduced the effects of Cylindrocladium black rot. A moist microclimate and maintenance of the peanut canopy by reduction in defoliation are factors that also enhance the development of southern stem blight of peanut (154).

In the present study, the development of the foliar canopy progressed through three general stages. For the first 40 days after planting, the canopy developed slowly and the foliage of individual plants remained separated from neighboring plants within the same row. By 40 days, the canopy within a row

had closed or was nearly closed, and the plants had entered the early stages of reproductive growth. Beyond 40 days, the canopy developed rapidly, as both the height and width were increasing. This vegetative growth occurred concurrently with the growth stages of pegging, pod development, and seed development. Eighty days after planting, the foliar canopy in both seasons had completely closed both within and between rows. Based on the measurements from the microclimates in 1999 (Figure 6-2), small drops in the temperature inside the canopy and in the pegging zone were associated with this period of canopy development and closure. Also, the relative humidity increased within the canopy beginning 50 days after planting (Figure 6-3). It is during these same periods that *C. parasiticum* and *S. rolfsii* became established in the peanut host (Figures 6-12 and 6-21).

Near the end of the season, the size of the canopy was reduced and it began to collapse. In 1999, it appeared that the decline in the canopy was probably the result of drought. Subsequent increases in the temperature within the canopy and in the soil and a decline in the relative humidity were likely the result of wilt associated with the drought.

Yield and Disease Severity

Southern stem blight and Cylindrocladium black rot were present in both years of this study. In 1998 and 1999, the largest yields and the least amount of wilt attributed to soilborne disease occurred in those peanuts treated with flutolanil twice during the season (Table 6-2). In both 1998 and 1999, plots treated with flutolanil had better yields, lower AUDPC values, and slower

epidemic rates than either the control or those plots treated with four applications of benomyl. The efficacy of flutolanil in the control of southern stem blight is documented in the literature (60, 112). In both 1998 and 1999, there was no significant difference in yield or disease severity between those plots treated with flutolanil and those treated with four applications of tebuconazole. Tebuconazole is also recognized as effective in the control of both southern stem blight and Cylindrocladium black rot (32, 33, 127, 148). However, in 1999, the yield and AUDPC values from plots treated with tebuconazole were not significantly different from the control plots or those treated with benomyl. This was largely the result of extremely high disease severity in a single plot among the whole plots treated with tebuconazole. The disease severities in the other three whole plots treated with tebuconazole were much lower.

Fungicide applications of benomyl and chlorothalonil or chlorothalonil alone were not effective to control diseases caused by soilborne fungal pathogens. There was a general trend for lower yields and increased disease severity when chlorothalonil was used with benomyl than when chlorothalonil was used alone. The use of benomyl may suppress *Trichoderma* spp., a natural biocontrol agent (Kucharek, personal communication). Backman et al. (10) observed that plots of Florunner peanuts treated with benomyl had a more severe incidence of southern stem blight than did any of the other plots in their study. Benomyl had no effect on *S. rolfsii in vitro*, but was toxic to *Trichoderma viride*. The incidence of *Trichoderma* spp. was not reduced in plots treated with

benomyl in Santa Rosa County (Figure 6-22). However, the ability of *Trichoderma* spp. to antagonize *S. rolfsii* may have been affected.

Fungal Incidence and Fungicide Treatments

It was not unusual to find significant differences among treatments in the incidence of a fungus on a single sampling date; however it was uncommon to find this repeated over sequential sampling dates (Figures 6-10 to 6-22). It was rare to find these patterns repeated in both seasons. The incidence of *R. solani* was lower on specific sampling dates in plots treated with tebuconazole than in the control plots was observed in both 1998 and 1999. A general trend for delayed infection and a reduction in the incidence of *S. rolfsii* in plots treated with flutolanil or tebuconazole from the control plots and those treated with benomyl was observed in 1998 and 1999. The inherent difficulty to sample for soilborne microorganisms and the resulting experimental error was likely involved in some of the variation between treatments and sampling dates. Importance was rarely given to significant differences that occurred among treatments on a single date.

Applications of tebuconazole, benomyl, and flutolanil did not affect the incidences of *A. flavus*, *A. niger*, *C. parasiticum*, *Fusarium* spp., *M. phaseolina*, *N. vasinfecta*, *Pythium* spp., *Rhizopus* spp., or *Trichoderma* spp. compared to the control of applications with only chlorothalonil (Figures 6-10,6-11,6-12,6-13,6-15,6-16,6-18, 6-20, and 6-22). Baird et al. (12, 13) found that the incidence of *Trichoderma* spp. was reduced on peanut pods from plants treated with flutolanil, while the incidence of *Fusarium* spp. increased. These results were not supported by the current study, though the reported incidences were from

the roots, hypocotyls, pods, and pegs, and not from the pods alone. The application of fungicides began 42 days after planting in 1998 and 45 days after planting in 1999, so that they would have limited effect on fungi that had infected the peanut plant prior to these dates. Fungi that were well established in the peanut plant by 42 or 45 days after planting included *A. flavus*, *A. niger*, *Fusarium* spp., *M. phaseolina*, *N. vasinfecta*, *Rhizopus* spp., and *Trichoderma* spp.

The incidence of *A. niger* and *Aspergillus* spp. on peanut can be reduced using fungicides. Brenneman et al. (34) found that the fungicide diniconazole did not reduce the isolation frequency of *Aspergillus flavus* from pods, but reduced the incidence on the kernels during a single year of their study. The fungicide significantly reduced the incidence of *A. niger* on the pods in both years of the study (34). Tebuconazole was found to reduce fungal colonization of peanut seeds by *Aspergillus* spp. (100), though the fungicide did not affect their incidences in the present study. Use of benomyl is recommended in Florida for control of diseases caused by *A. niger* (114). The efficacy of this fungicide may be related to an ability to reduce the growth or activity of *A. niger* rather than an ability to reduce incidence once it has become established in the host. Benomyl did not reduce the incidence in this study.

Cylindrocladium parasiticum was not established in the peanut by 42 or 45 days after planting. Yet its incidence was not different from levels in the control plots by applications of benomyl, tebuconazole, or flutolanil, though benomyl and tebuconazole are recommended for management of

Cylindrocladium black rot (114, 127). These fungicides may suppress the symptoms associated with Cylindrocladium black rot by inhibiting the growth of the pathogen, though not actually reducing the incidence of the pathogen.

In at least one of the two years, the incidences of *L. theobromae*, *Phomopsis* sp., *R. solani*, and *S. rolfsii* appeared to be suppressed by the application of fungicides (Figures 6-14, 6-17,6-19,6-21). *Phomopsis* sp. and *S. rolfsii* are clearly associated with the reproductive growth stages and the latter part of the season, so that applications of fungicides beginning 42 and 45 days after planting are appropriate. In 1998, applications of benomyl appeared to suppress infection by *Phomopsis* sp. In 1998 and in 1999, applications of flutolanil and tebuconazole were associated with reduced incidences of *S. rolfsii*.

The reduction in the incidence of *S. rolfsii*, the causal agent of southern stem blight, may be an important reason for the increased yields and decreased disease severity in plots sprayed with either flutolanil or tebuconazole. Although the severity of southern stem blight and not the incidence of *S. rolfsii* in plants from treated plots is reported in most studies, the use of these two compounds in the management of southern stem blight has been well documented (16, 30, 33, 60, 70, 112). The incidence of *S. rolfsii* in plots in which benomyl was applied were at times significantly greater than in plots sprayed only with chlorothalonil, which supports earlier findings (10).

In 1998, the incidence of *R. solani* was lower in plots that received tebuconazole than in the control at 70, 84, and 98 days after planting, and in 1999, the incidence in the plots that received tebuconazole was lower at 59 and

81 days after planting (Figure 6-19). Although *R. solani* is well established prior to 42 or 45 days after planting, it is near this time that a natural reduction in incidence is observed. Such declines in incidence were not only seen in this study, but were also observed in the field experiments conducted in Quincy, Florida (Figure 5-20). Similar declines in incidence have been reported in wheat (88). Applications of tebuconazole are reported to reduce the severity of Rhizoctonia limb rot (32, 33, 148). Baird et al. (13) found that the incidence of *R. solani* was significantly reduced on pods treated with flutolanil. Flutolanil did not reduce the incidence of *R. solani* in this study.

In 1998, the incidence of *L. theobromae* was suppressed in plots treated with benomyl when compared to plots only treated with chlorothalonil, and in 1999, the incidence of the pathogen appeared to suppressed in plots treated with tebuconazole at 59 and 94 days after planting (Figure 6-14). In Florida, benomyl is recommended for the control of Diplodia collar rot (114). In Virginia, the incidence of Diplodia collar rot was not affected by the use of azoxystrobin, tebuconazole, iprodione, flutolanil, or fluazinam (139). Yields increased significantly in plots where azoxystrobin and fluazinam were applied, though these increases were not associated with visible suppression of Diplodia collar rot (139).

Natural Associations of Soilborne Fungi

Two communities of soilborne fungi were found to be associated with peanut (Chapter 4). A general community of soilborne fungi was associated with the peanut plant and its diversity increased through at least three stages of

development. The fungi that made up this community were grouped based upon the conditions upon which they attained some relative abundance. The development of the general community included the foundational, secondary, and tertiary stages. The peg community emerged later in the season with the tertiary stage and contained fungi that were associated with foliar diseases.

A primary objective in this study was to determine if the two communities of soilborne fungi identified in earlier surveys were affected by the use of different fungicide programs. Literature to address this topic is sparse. Kuthubutheen (115) isolated over 40 species and 23 genera of fungi from the reproductive structures of rice as they progressed from flowers prior to the emergence of panicles through seed set before harvest. The number of species that were isolated increased with emergence of sequential reproductive stages and the relative abundance of specific fungi was affected by the growth stage of the host. Consistently fewer species of fungi were isolated from the reproductive structures after applications of thiophanate-methyl, thiram, and agallol than from untreated rice plants (115). Fungi that tended to persist after sprays with these fungicides included *Curvularia* spp. and *Alternaria alternata*. In another study, the composition of the mycoflora on peach twigs was affected by applications of the fungicides captan, dinocap, benomyl, and methomyl (63). On untreated peach twigs, common fungi included *Alternaria* spp., *Cladosporium* spp., and *Penicillium* spp. However, on the treated twigs, populations of both *Cladosporium* spp., and *Alternaria* spp. were reduced. Some fungi, including

Leptosphaeria coniothyrium, *Phoma* sp., and *Aspergillus candidus*, were only isolated from twigs that were not treated with fungicides (63).

The general patterns for changes in incidences of the 13 soilborne fungi over a season were similar among the four fungicide treatments (Figures 6-10 through 6-22). The relationships among the incidences of these fungi, the growth stage of the host, and part of plant from which they were isolated can be further understood with Figures 6-4 through 6-7. As in Chapter 5, the incidences of soilborne fungi were positioned in two groups, one centered on the origin and the other associated with the latest sampling dates and growth stages approaching harvest maturity. Some fungi were clustered with the hypocotyls, the pegs, and the roots and pods, though most points were clustered at the origin which meant there was a general distribution in all parts of the plant (Figures 6-6 and 6-7).

The composition of the peg community was different in 1998 and 1999 in Santa Rosa County than it was as described from the general survey of 1995 and 1996. *Phomopsis* sp., because of its close association with the pegs and the later reproductive stages, remained an important member of this community. However, *S. rolfsii* would not be considered to be a part of the peg community because it was associated with other parts of the plant in addition to the pegs. Based on the close association between the incidences of *L. theobromae* and the pegs for all treatments except for the control, it appears that this fungus may be associated with the peg community. This may be an example of a shift in the composition of a community based upon the application of fungicides. The

incidences of *L. theobromae* from plots treated with tebuconazole, benomyl, and flutolanil were more closely associated with the pegs of the peanut plant while the incidence of *L. theobromae* in plants sprayed only with chlorothalonil was more generally distributed within the plant. *Lasiodiplodia theobromae* generally emerged in the latter part of the season, though in 1999, it was commonly isolated by 25 days after planting. The reason for this is unknown, but there were other reports in Santa Rosa County that year of many young plants in specific fields being killed by Diplodia collar rot (J. Atkins, County extension agent, personal communication).

The composition of the fungi associated with both the foundational stage and the secondary stage in the development of the general community was very similar to that found in 1995 and 1996. *Fusarium* spp. clearly emerged during the foundational stage (Figure 6-13) and was generally associated with all of the parts of the peanut plant. The incidences of *Trichoderma* spp. and *A. niger* also appeared early in the season, but not with the same magnitude as *Fusarium* spp. They could be included in either the foundational or the secondary stage of development. The incidences of *N. vasinfecta*, *R. solani*, *M. phaseolina*, and *Rhizopus* spp. placed them in the secondary stage of development, though they were isolated from seedlings. *Neocosmospora vasinfecta* and *M. phaseolina* tended to be associated more closely with roots and pods, while the incidence of *R. solani* was more generally distributed.

The fungi that were associated with the tertiary stage of development included *C. parasiticum*, *S. rolfsii*, and *L. theobromae*. The placement of *C.*

parasiticum within the tertiary stage was evident from the plots generated with correspondence analysis as it was associated with the latter part of the season and was generally found associated with the roots, pods, and pegs. *Sclerotium rolfsii* is also associated with the latter sampling dates, though this was less obvious with some fungicide treatments (Figures 6-4 and 6-5). However, it was clear that *S. rolfsii* emerged at the end of the season (Figure 6-21). In 1998 and 1999, this fungus was more generally distributed, while in 1995 and 1996 it was specifically associated with the pegs. In 1998 and 1999, limbs from the crown of the peanut plants with lesions were analyzed with the hypocotyls, a practice that was not followed during the earlier surveys. Isolations of *S. rolfsii* from these lesions would shift the association of the pathogen from the pegs to a more general position.

The incidences of *A. flavus* and *Pythium* spp. were generally distributed in time and space and thus they probably emerged during the secondary stage of the development of the general community. Low incidence of *Pythium* spp. made it difficult to assign it to one stage of development. The incidence of *Rhizopus* spp. was also generally distributed in time, but was more closely associated with the hypocotyl region and thus was placed in either the foundational or the secondary stage of development.

Disease Severity Associated with Incidences of Fungi

The general severity of disease of the plants sampled within plots sprayed with each fungicide treatment is reflected in the segregation of points in Figures 6-19 and 6-20. In 1998, the incidences of fungi from plots treated with flutolanil

and tebuconazole were distributed vertically and are generally associated with a healthier rating than the fungi from the control or the benomyl treatments. These findings, based upon the evaluations of individual plants, were similar to disease severity within the whole plots measured with the AUDPC and the epidemic rate (Table 6-2). In 1999, the incidences of fungi from those plots treated with flutolanil were associated with the healthiest ratings while those from the control plots and the plots treated with benomyl were again associated with the greatest disease severity. Those fungi associated with the greatest disease severity in both years included *C. parasiticum* for all treatments and *S. rolfsii* from the control and from the benomyl plots.

Conclusions

The largest yields and lowest disease severity in this study were associated with the use of flutolanil during the season. The smallest yields and greatest disease severity were associated with plants sprayed with only chlorothalonil or with benomyl and chlorothalonil. Use of tebuconazole produced results similar to the use of flutolanil in 1998, though this fungicide was less effective in 1999. This was primarily due to severe disease in a single plot treated with tebuconazole.

There was evidence that the development and closure of the foliar canopy may be associated with changes in the microclimate of the crown and pegging zones. These changes, including a reduction in temperature and an increase in relative humidity, may explain part of the reason for the appearance of Cylindrocladium black rot and southern stem rot later in the season.

None of the fungicide programs reduced the incidence of *C. parasiticum*, though flutolanil and tebuconazole were associated with a reduction in the incidence of *S. rolfsii*. Control of Cylindrocladium black rot may not be achieved by a reduction in the incidence of *C. parasiticum*, but may be influenced by a reduction in the growth of the pathogen and a suppression of symptoms associated with the disease. Tebuconazole was associated with a reduced incidence of *R. solani* on three dates in 1998 and two dates in 1999 after the fungicide had been applied. In 1998, benomyl was associated with a reduced incidence of L. theobromae on two dates after the fungicide had been applied. In 1999, tebuconazole was associated with a reduced incidence of *L. theobromae* on two dates after the fungicide had been applied.

The composition and development of the general community of soilborne fungi and the community of peg fungi were similar in peanut from two fields in Santa Rosa County in 1998 and 1999 to that observed in 1995 and 1996. It is difficult to differentiate the foundational and secondary stages of the general community using results from a single field, but it is clear that *Fusarium* spp. belongs with the early foundational stage. In this study, *S. rolfsii* was not grouped with the peg-community but it was grouped with the tertiary stage of the general community because of association with parts other than the pegs. *Lasiodiplodia theobromae* from plots treated with only chlorothalonil appears generally associated with the hypocotyls, roots, pegs, and pods of the peanut plant, while in the treatments with flutolanil, benomyl and tebuconazole, it is more closely associated with the pegs. If the use of these fungicides restricts the

incidence of this pathogen to the pegs, then this would be an example of a change in community structure through a shift of a fungus from the tertiary stage of the general community to the peg community.

CHAPTER 7
INFLUENCE OF FOLIAR DISEASE ON SOILBORNE FUNGI

Introduction

Three economically important foliar diseases, as well as several diseases of lesser importance, affect crops of peanut in Florida. The three important diseases are early leaf spot, caused by *Cercospora arachidicola* S. Hori, late leaf, spot caused by *Cercosporidium personatum* (Berk. & M. A. Curtis) Deighton, and rust, caused by *Puccinia arachidis* Speg. Growers in Florida can manage these diseases by crop rotation, careful site selection, land preparation, the use of fungicides, and use of cultivars with partial resistance (114). Failure to control these diseases can result in severe defoliation of the peanut plants followed by reductions in yield as great as 70% (130).

Defoliation of peanut by *C. arachidicola* and *C. personatum* results in changes in the photosynthetic rate of the plants, lower CO_2 exchange rates within the canopy because of incomplete light interception, and altered partitioning of photosynthates (174). Control of leaf spot in Florunner resulted in greater weights of stems, leaves, lateral roots, and pods. Low rates of chlorothalonil and increased disease severity were associated with weaker pegs and earlier pod maturity that resulted in more pods remaining in the soil at harvest.

The effects of foliar diseases and tactics to control these diseases on the development of soilborne diseases in peanut have not been thoroughly evaluated. Stresses to plants that reduce photosynthesis, such as foliar diseases, can predispose the plants to infection and diseases caused by soilborne pathogens that would have occurred to a lesser extent or not at all (117). However, Backman et al. (10) found that the use of benomyl in the control of leaf spot of peanut led to greater severity of southern stem blight caused by *Sclerotium rolfsii*.

Sclerotium rolfsii and *Cylindrocladium parasiticum* cause severe diseases of peanut. The development of southern stem blight is greater under conditions, such as irrigation and control of leaf spot diseases and insects, that promote the development of a dense foliar canopy (145, 154). Greater infection of the roots of the peanut plant by *C. parasiticum* occurs at 25° C than at 30° C, and little or no disease develops in soil where the temperature is 35° C or greater (137). Management of foliar diseases of peanut and a reduction in the defoliation of the foliar canopy could maintain a microclimate well suited for the development of these and other soilborne diseases, such as Rhizoctonia limb rot.

The objectives of the research presented in this chapter were to observe if the control of foliar disease in peanut had any affect on the severity of disease caused by soilborne fungal pathogens, the incidences of soilborne pathogens, or the composition of the community of soilborne fungi observed in a general survey. The severity of the foliar disease in a commercial field was controlled

using two rates of the fungicide chlorothalonil. The development of both foliar and soilborne disease was evaluated throughout a field season.

Material and Methods

This study was conducted during 1998 in a commercial field in Suwannee County, Florida near the town O'Brien. This field was selected because of historically high incidence of southern stem blight (Kucharek, personal communication). Pivot irrigation was available, but was used infrequently during the season despite drought-like conditions. The field had been planted to Bahia grass for the previous six years.

Field Plots and Experimental Design

The field was planted on 3 June 1998 with the cultivar 'Georgia Green' and maintained with normal commercial practices. The field plots were established on 11 June using a split-plot experimental design. Each whole plot was four rows wide by 15.2 meters long. Whole plots were replicated four times in the field. Each subplot was four rows wide by 1.52 meters long. Ten subplots were randomized within each whole plot, though only eight were sampled in this study.

The experiment consisted of three whole plot and eight subplot treatments. The whole plot treatments were the levels of spray with chlorothalonil (tetrachloroisophthalonitrile, Bravo-Ultrex® 82.5 WDG) to control foliar disease. The treatments included a control that received no chlorothalonil during the season, a mid-level rate of chlorothalonil at 680 g ha^{-1} (0.6 lbs A^{-1}), and a high level of chlorothalonil at 2040 g ha^{-1} (1.8 lbs A^{-1}). The labeled rate for

this compound is 158 g ha^{-1} (1.4 lbs A^{-1}). The high rate of fungicide application used in this study was selected to insure that the incidence of foliar disease in those plots was minimal compared to the unsprayed control. Applications of the fungicide treatments began on 7 July and continued on a biweekly basis through the end of the season (Table 7-1). Fungicides were applied using a CO_2 backpack sprayer. The spray pressure was 207 kPa (30 PSI); the spray boom had two fan-nozzles spaced 91.4 cm apart to accommodate the row spaceing. The fungicides were applied using a spray volume of 236.5 L ha^{-1} (25 gal A^{-1}).

Canopy Development

The foliar canopy within each appropriate subplot was assessed on each sampling date by measuring the height and width of the canopy at a typical point. The values of the height and the width were multiplied and then averaged across the four replications within each whole plot treatment on a sampling date.

The subplot treatments represented the order of biweekly sampling dates throughout the season. The ninth and tenth subplots within each whole plot were designed to allow changes in subplot designations in the event that a subplot was unusable due to loss of plants for some reason. The first subplot within each whole plot was sampled on 23 June, 20 days after planting. The remaining subplots were sampled on a biweekly basis until the end of the season.

Soil Sampling

Soil samples were collected from the seedbeds within each replication of the field plots on 11 June 1998. Each replication of whole plots (12 rows) was

Table 7-1. Sampling information from a leaf spot trial for peanut, Suwannee County, Florida 1998.

		1998		
Event	Fungicide rate	Date	Days after planting	Median growth stage[y]
Planting		3 Jun		
Sample 1		23 Jun	20	
	Control			V4
	Low			V4
	High			V4
Sample 2		7 Jul	34	
	Control			V6-V7
	Low	*[z]		V6
	High	*		R1
Sample 3		21 Jul	48	
	Control			R2
	Low	*		R2
	High	*		R2
Sample 4		4 Aug	62	
	Control			R4
	Low	*		R4
	High	*		R4
Sample 5		18 Aug	76	
	Control			R5
	Low	*		R5
	High	*		R5
Sample 6		4 Sept	93	
	Control			R6-R7
	Low	*		R6
	High	*		R6-R7
Sample 7		21 Sept	110	
	Control			R7
	Low	*		R7
	High	*		R7-R8
Sample 8		5 Oct	124	
	Control			R8
	Low	*		R8
	High	*		R8
Harvest		19 Oct	138	

[y] A summary of the growth stages of the peanut plant is presented in Table 3-5; briefly, V1-V6 = vegetative stages in increasing maturity and R = reproductive stages with R1 = beginning bloom, R2 = beginning peg, R3 = beginning pod formation, R4 = full pod formation, R5 = beginning seed formation, R6 = the full seed stage of development, R7 = beginning maturity, and R8 = harvest maturity of the pods.

[z] * = fungicide treatments were applied on this date.

divided across the rows into strips that were 3.05 m wide. One soil sample was collected within the seedbed along each row and the twelve samples from each strip were pooled and chilled until they could be analyzed. Core samples were taken to a depth of 12.7 cm and were approximately 2 cm in diameter. The soil that was collected was later analyzed for *S. rolfsii* and *C. parasiticum* as described earlier in the materials and methods section of Chapter 5.

Plant Sampling

The rows of peanut ran from east to west in this study. Within each subplot, plants were destructively sampled from within the two northern rows. No plants were sampled from the two southern rows that were used to measure disease severity. On each sampling date, five plants were destructively sampled from the two northern rows in the appropriate subplot. The plants that were sampled were selected based upon their position in the subplot and without regard or preference to their apparent health. The plants were removed with a shovel to include as many of the roots, pods, and pegs as possible with the sample. Excess foliage was removed in the field so that the final sample consisted of roots, pegs, pods, the hypocotyls and crown regions, and some foliage. The samples from a subplot were bagged together and placed into an ice cooler until they could be refrigerated in the laboratory.

Leaf Sampling

On each sampling date, five leaves were randomly sampled from within each of the two rows of the appropriate subplots (a total of 10 leaves). Disease severity was assessed by estimating the percentage of each leaf surface that

was covered with leaf spots and rust pustules. The assessments were made for the total diseased area on each leaf, whether the disease was the result of *C. archidicola, C. personatum*, or *P. arachidis*. The vast majority of foliar disease during this study was caused by *P. arachidis*. The final value given for severity of foliar disease within each plot on a given day was calculated as the mean of the 10 sampled leaves.

Estimation of Soilborne Disease

The severity of soilborne disease within each whole plot was measured based upon the length of wilted row within each of the two unsampled rows per sampling date. Wilt that was clearly the result of tomato spotted wilt virus was not included in this total, though the incidence of TSWV was extremely low in this field during 1998. The length of wilted row was then used to calculate the area under the disease progress curve for each whole plot.

Processing of Samples

Once the plants were returned to the laboratory, they were processed as described in the materials and methods section of Chapter 3.

Selected Fungi

The incidences of 14 different fungi on the underground parts of the peanut plant were evaluated during this study in relation to time of season, part of the plant, and rating of the plant. These fungi were selected from the large group of soilborne fungi found in association with the peanut plant based upon their importance as pathogens, there potential roles as antagonists for fungal pathogens, or their interesting growth habits. The pathogens included

Aspergillus flavus, Aspergillus niger, C. parasiticum, Lasiodiplodia theobromae, Macrophomina phaseolina, Neocosmospora vasinfecta, Pythium spp., *Rhizoctonia solani, Rhizopus* spp., and *S. rolfsii.* The possible antagonists included *Trichoderma* spp. and *Zygorhynchus* sp. *Phomopsis* sp. was included because of its interesting association with the pegs of the plant, and only infrequently with the other parts.

Analysis

The severity of disease associated with soilborne pathogens and foliar pathogens was analyzed by running a linear regression on the means of the AUDPC values associated with each whole plot treatment. The mean yield response from each whole plot treatment was also analyzed by simple linear regression. The incidence of the fungi isolated from the plants on each sampling date was analyzed by analysis of variance and the least significant difference method to determine difference between fungicide treatments on each sampling date. The correspondence analysis procedure was used on the data to elucidate relationships between the incidences of the selected fungi, the time of the season when the isolations occurred, the health rating of the plants, the parts of the plant from which the fungi were isolated, and the fungicide treatment. Fungi that were grouped together in the drawn plots created from correspondence analysis were circled to facilitate interpretation.

Results

A severe epidemic of peanut rust developed late in the season during this study. Although an odd leaf spot, tentatively described as a variant of early leaf

spot (Kucharek, personal communication), was observed earlier in the season, by the later part of the season nearly all of the disease was the result of *P. arachidis*. At one time, this commercial field in Suwannee County had a high incidence of southern stem blight; however after 6 years in bahiagrass, the importance of this disease was minimal. In fact, the incidence of important soilborne pathogens was minimal. *Cylindrocladium parasiticum*, *Pythium* spp., and *S. rolfsii* were not isolated from any plants during this study:

Canopy Development

The foliar canopies in the plots within the three treatments followed similar growth patterns (Figure 7-1). The development of the canopies progressed through three stages. The first occurred early in the season until about 40 days after planting and was characterized by slow growth. After approximately forty days, the canopy began to develop rapidly and reached its maximum size somewhere between 80 and 100 days after planting. After this peak, the size of the canopy slowly declined, largely due to a reduction in height. The foliar canopy was complete, or nearly so, by 76 days after planting.

Peanuts sprayed with various rates of chlorothalonil produced higher yields and lower severity of foliar disease, but did not affect the severity of soilborne disease (Figures 7-2, 7-3, and 7-4). The responses of yield and disease severity versus the fungicide rate were calculated by plotting the best-fit lines between the mean values calculated from the four replications of each whole plot treatment. Presented on each graph are the equations for the best-fit line and the R^2-values for those lines. The incidences of the soilborne fungi

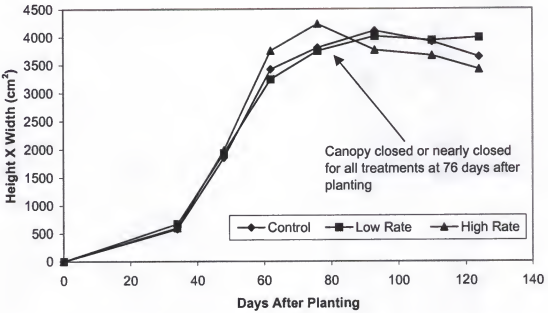


Figure 7-1. Development of the foliar canopies associated with three rates of chlorothalonil (0 g ha^{-1}, 680 g ha^{-1}, and 2040 g ha^{-1}) sprayed for control of leaf spot and rust in peanut. The data were collected in 1998 in a commercial field in Suwannee County, Florida. The development of the canopy was described by the product of the height and the width of the canopy measured at a single representative point in each subplot sampled on a given date. The points on the graph represent the mean value for each fungicide treatment at each date.

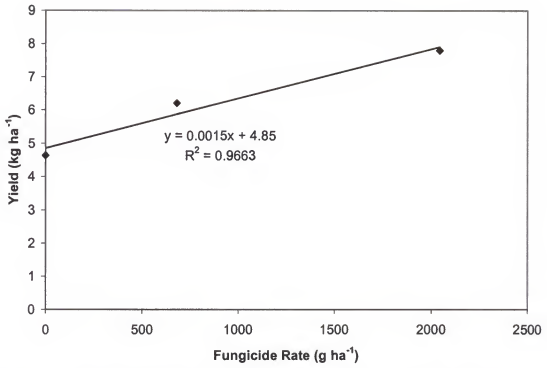


Figure 7-2. The effect of the rate of the fungicide chlorothalonil applied on a biweekly basis throughout the season on the yield of peanut in a commercial peanut field in Suwannee County, Florida, in 1998.

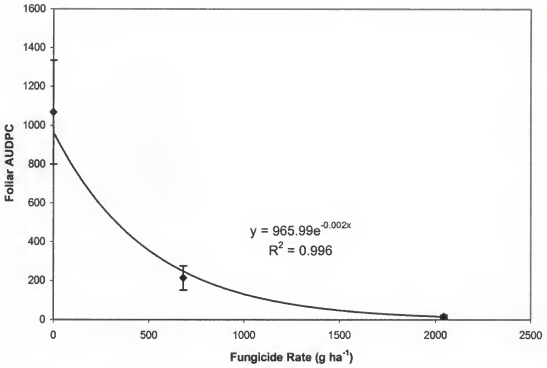


Figure 7-3. The effect of the rate of the fungicide chlorothalonil applied on a biweekly basis on the area under the disease progress curve (AUDPC) for the severity of foliar disease in a commercial field of peanut in Suwannee County, Florida during 1998. Most of the disease was peanut rust caused by *Puccinia arachidis*.

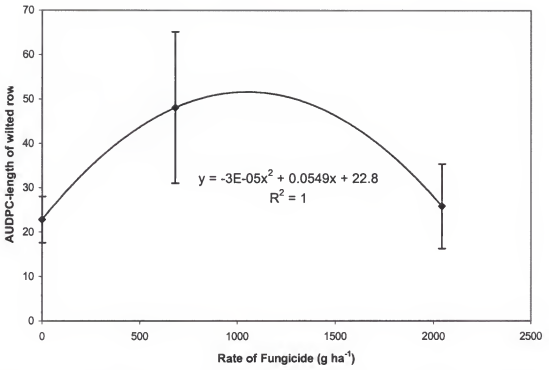


Figure 7-4. The effect of the application of the fungicide chlorothalonil on the area under the disease progress curve (AUDPC) associated with soilborne disease in a commercial field of peanut in Suwannee County, Florida during 1998.

evaluated in this study were not affected by the fungicide treatments for the control of foliar diseases (Figures 7-5 through 7-15).

By correspondence analysis, points to represent the incidence of fungi were positioned in three clusters in relation to the time of sampling and growth stage of the host (Figure 7-16). The sampling dates, represented by T1 through T8 were positioned along the horizontal axis. The largest group was centered around the origin. This was interpreted as these fungi were more generally associated over the entire season and less associated with particular stages of growth. A second group, composed of *Zygorhynchus* sp. (14B, C), *A. flavus* (1A, B), and *Rhizopus* spp. (11B, C), was more prominently associated with the pegging growth stage at T3. The final group included *R. solani* (10A, B, C), *L. theobromae* (5A, B, C), and *Phomopsis* sp. (8A, B, C), and was clustered at the end of the season with T8.

In this field study, the incidences of *L. theobromae* (5A, B, C) and *Phomopsis* sp. (8A, B) were closely associated with the pegs (P4) (Figure 7-17). The incidence of *N. vasinfecta* (7A, B, C) was associated with the roots (P3). The associations of the other fungi with parts of the peanut plant were more general. However, the incidences of *A. niger* (2A, B, C), and *R. solani* (10A, B, C) were more closely associated with the hypocotyls (P2), roots (P3), and pegs (P4), while *Rhizopus* spp. (11A, B, C), *Zygorhynchus* sp. (14A, B, C), and *A. flavus* (1A, B, C) were more closely associated with the total plant (P1) and the roots (P3).

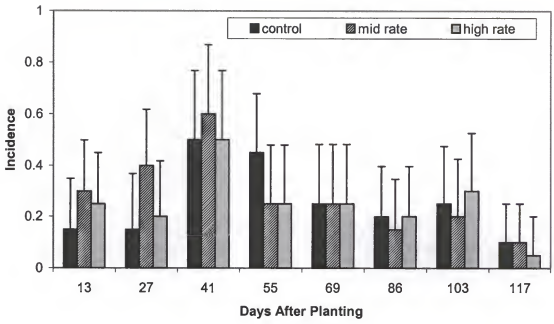


Figure 7-5. Incidence of *Aspergillus flavus* measured as the proportion of infected peanut plants sampled on each date from plots that received three different rates of chlorothalonil (0 g ha^{-1}, 680 g ha^{-1}, and 2040 g ha^{-1}) to control foliar fungal diseases in a commercial field in Suwannee County, Florida, in 1998. The mean incidence was calculated by analysis of variance; error bars represent the results of mean comparison by the least significant difference test at the $\alpha = 0.1$ level. Error bars represent differences on a single date.

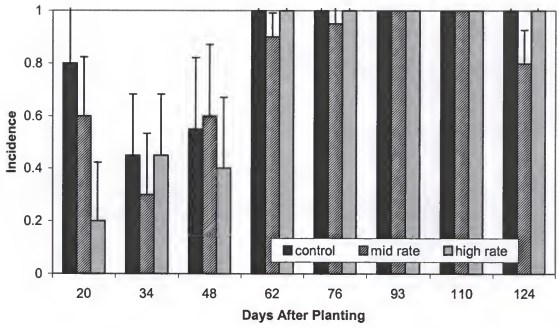


Figure 7-6. Incidence of *Aspergillus niger* measured as the proportion of infected peanut plants sampled on each date from plots that received three different rates of chlorothalonil (0 g ha^{-1}, 680 g ha^{-1}, and 2040 g ha^{-1}) to control foliar fungal diseases in a commercial field in Suwannee County, Florida, in 1998. The mean incidence was calculated by analysis of variance; error bars represent the results of mean comparison by the least significant difference test at the $\alpha = 0.1$ level. Error bars represent differences on a single date.

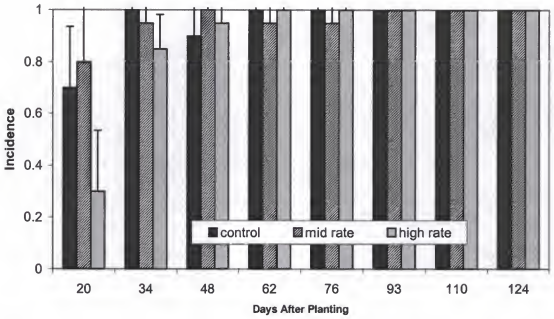


Figure 7-7. Incidence of *Fusarium* spp. measured as the proportion of infected peanut plants sampled on each date from plots that received three different rates of chlorothalonil (0 g ha^{-1}, 680 g ha^{-1}, and 2040 g ha^{-1}) to control foliar fungal diseases in a commercial field in Suwannee County, Florida, in 1998. The mean incidence was calculated by analysis of variance; error bars represent the results of mean comparison by the least significant difference test at the $\alpha = 0.1$ level. Error bars represent differences on a single date.

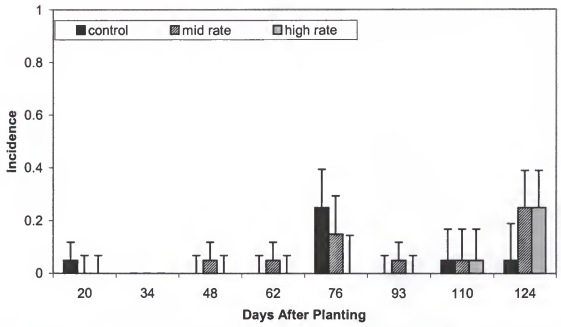


Figure 7-8. Incidence of *Lasiodiplodia theobromae* measured as the proportion of infected peanut plants sampled on each date from plots that received three different rates of chlorothalonil (0 g ha^{-1}, 680 g ha^{-1}, and 2040 g ha^{-1}) to control foliar fungal diseases in a commercial field in Suwannee County, Florida, in 1998. The mean incidence was calculated by analysis of variance; error bars represent the results of mean comparison by the least significant difference test at the $\alpha = 0.1$ level. Error bars represent differences on a single date.

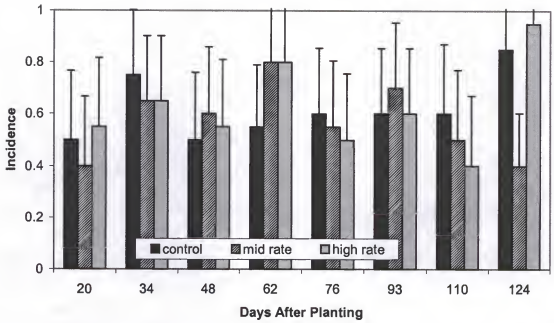


Figure 7-9. Incidence of *Macrophomina phaseolina* measured as the proportion of infected peanut plants sampled on each date from plots that received three different rates of chlorothalonil (0 g ha^{-1}, 680 g ha^{-1}, and 2040 g ha^{-1}) to control foliar fungal diseases in a commercial field in Suwannee County, Florida, in 1998. The mean incidence was calculated by analysis of variance; error bars represent the results of mean comparison by the least significant difference test at the $\alpha = 0.1$ level. Error bars represent differences on a single date.

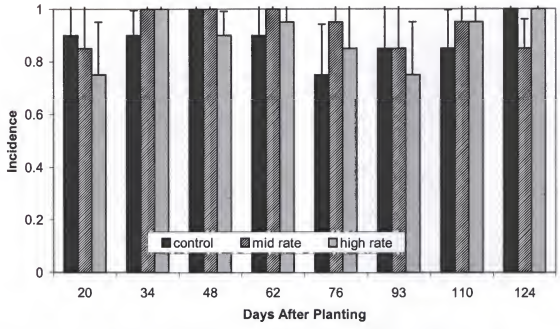


Figure 7-10. Incidence of *Neocosmospora vasinfecta* measured as the proportion of infected peanut plants sampled on each date from plots that received three different rates of chlorothalonil (0 g ha^{-1}, 680 g ha^{-1}, and 2040 g ha^{-1}) to control foliar fungal diseases in a commercial field in Suwannee County, Florida, in 1998. The mean incidence was calculated by analysis of variance; error bars represent the results of mean comparison by the least significant difference test at the $\alpha = 0.1$ level. Error bars represent differences on a single date.

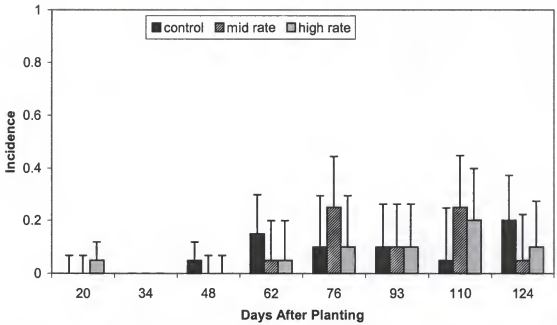


Figure 7-11. Incidence of *Phomopsis* spp. measured as the proportion of infected peanut plants sampled on each date from plots that received three different rates of chlorothalonil (0 g ha^{-1}, 680 g ha^{-1}, and 2040 g ha^{-1}) to control foliar fungal diseases in a commercial field in Suwannee County, Florida, in 1998. The mean incidence was calculated by analysis of variance; error bars represent the results of mean comparison by the least significant difference test at the $\alpha = 0.1$ level. Error bars represent differences on a single date.

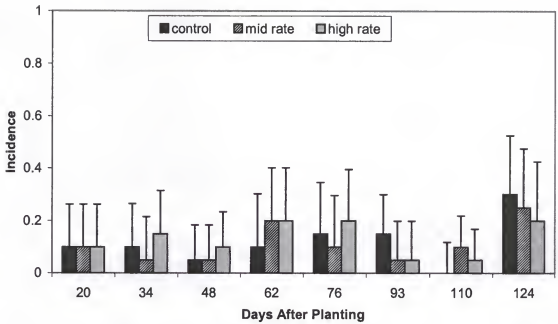


Figure 7-12. Incidence of *Rhizoctonia solani* measured as the proportion of infected peanut plants sampled on each date from plots that received three different rates of chlorothalonil (0 g ha^{-1}, 680 g ha^{-1}, and 2040 g ha^{-1}) to control foliar fungal diseases in a commercial field in Suwannee County, Florida, in 1998. The mean incidence was calculated by analysis of variance; error bars represent the results of mean comparison by the least significant difference test at the $\alpha = 0.1$ level. Error bars represent differences on a single date.

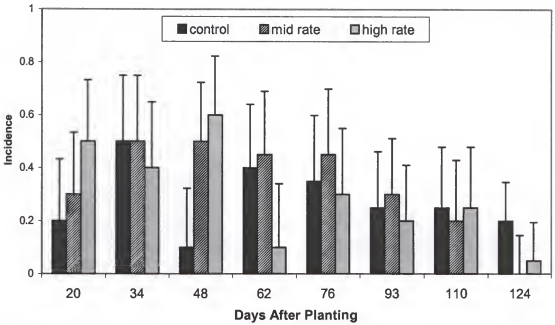


Figure 7-13. Incidence of *Rhizopus* spp. measured as the proportion of infected peanut plants sampled on each date from plots that received three different rates of chlorothalonil (0 g ha^{-1}, 680 g ha^{-1}, and 2040 g ha^{-1}) to control foliar fungal diseases in a commercial field in Suwannee County, Florida, in 1998. The mean incidence was calculated by analysis of variance; error bars represent the results of mean comparison by the least significant difference test at the $\alpha = 0.1$ level. Error bars represent differences on a single date.

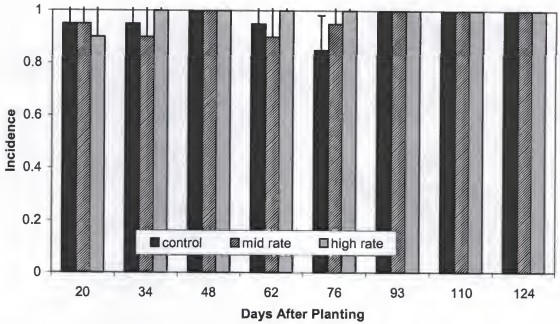


Figure 7-14. Incidence of *Trichoderma* spp. measured as the proportion of infected peanut plants sampled on each date from plots that received three different rates of chlorothalonil (0 g ha^{-1}, 680 g ha^{-1}, and 2040 g ha^{-1}) to control foliar fungal diseases in a commercial field in Suwannee County, Florida, in 1998. The mean incidence was calculated by analysis of variance; error bars represent the results of mean comparison by the least significant difference test at the $\alpha = 0.1$ level. Error bars represent differences on a single date.

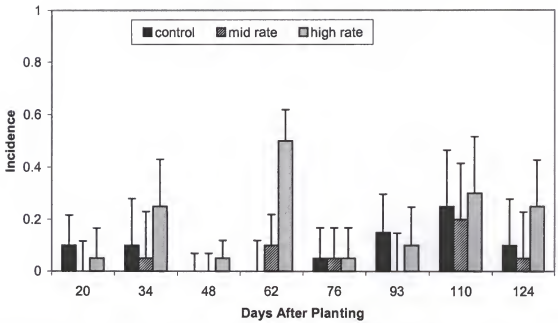


Figure 7-15. Incidence of *Zygorhynchus* spp. measured as the proportion of infected peanut plants sampled on each date from plots that received three different rates of chlorothalonil (0 g ha^{-1}, 680 g ha^{-1}, and 2040 g ha^{-1}) to control foliar fungal diseases in a commercial field in Suwannee County, Florida, in 1998. The mean incidence was calculated by analysis of variance; error bars represent the results of mean comparison by the least significant difference test at the $\alpha = 0.1$ level. Error bars represent differences on a single date.

Figure 7-16. Simple correspondence analysis from 1998 to establish the relationship between the time of sampling and the incidence of specific fungi isolated from three treatments to control foliar diseases. The variables T1 through T8 represent the eight sequential sampling dates during the field season. The letters A, B, and C represent the rate of chlorothalonil applied to the peanut plants from which the isolations were made. The control is represented by A, the middle rate by B, and high rate by C. The fungi are represented as follows: *Aspergillus flavus* (1), *Aspergillus niger* (2), *Cylindrocladium parasiticum* (3), *Fusarium* spp. (4), *Lasiodiplodia theobromae* (5), *Macrophomina phaseolina* (6), *Neocosmospora vasinfecta* (7), *Phomopsis* sp. (8), *Pythium* spp. (9), *Rhizoctonia solani* (10), *Rhizopus* spp. (11), *Sclerotium rolfsii* (12), *Trichoderma* spp. (13), and *Zygorhynchus* sp. (14). Units on the horizontal and vertical axes were not defined when the results from correspondence analysis were plotted.

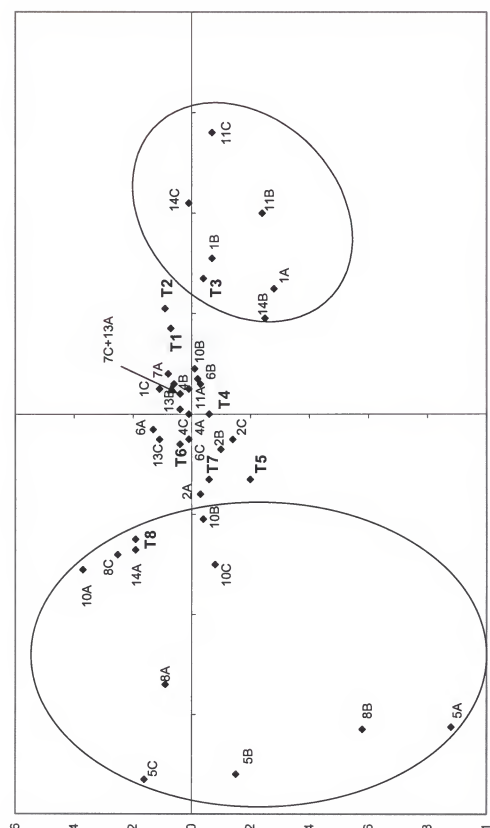
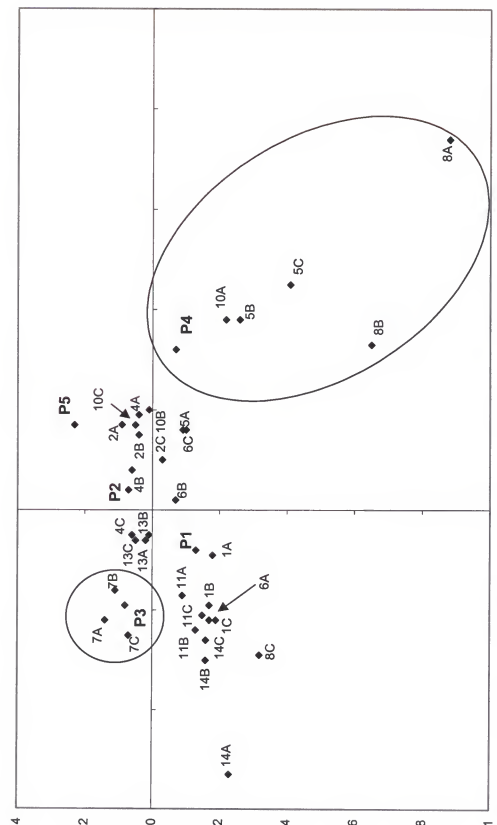

0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
T1
T2
T3
T4
T5
T6
T7
T8
7C+13A
1C
7A
13B
7B
11A
10B
6B
6A
13C
4C
6C
4A
2B
2C
2A
10B
10C
14A
8C
10A
8A
5C
5B
8B
5A
14C
11C
11B
1B
1A
14B

Figure 7-17. Simple correspondence analysis from 1998 to establish the relationship between the parts of the plant and the incidence of specific fungi isolated from three treatments to control foliar diseases. The variables P1 through P5 represent the five parts of the plant from which fungi were isolated. The total plant is represented by P1, hypocotyls by P2, roots by P3, pegs by P4, and the pods by P5. . The letters A, B, and C represent the rate of chlorothalonil applied to the peanut plants from which the isolations were made. The control is represented by A, the middle rate by B, and high rate by C. The fungi are represented as follows: *Aspergillus flavus* (1), *Aspergillus niger* (2), *Cylindrocladium parasiticum* (3), *Fusarium* spp. (4), *Lasiodiplodia theobromae* (5), *Macrophomina phaseolina* (6), *Neocosmospora vasinfecta* (7), *Phomopsis* sp. (8), *Pythium* spp. (9), *Rhizoctonia solani* (10), *Rhizopus* spp. (11), *Sclerotium rolfsii* (12), *Trichoderma* spp. (13), and *Zygorhynchus* sp. (14). Units on the horizontal and vertical axes were not defined when the results from correspondence analysis were plotted.


P1
P2
P3
P4
P5
1A
1B
1C
2A
2B
2C
4A
4B
4C
5A
5B
5C
6A
6B
6C
7A
7B
7C
8A
8B
8C
10A
10B
10C
11A
11B
11C
13A
13B
13C
14A
14B
14C
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1

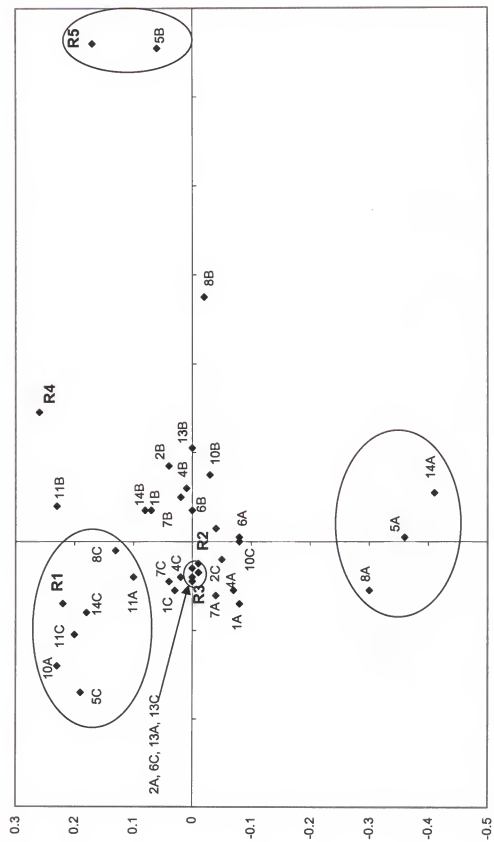
The incidences of most fungi in this study were not associated with a specific health rating, but were clustered around the origin (Figure 7-18). Only *L. theobromae* (5B) from the plots treated with the low rate of chlorothalonil was disproportionately associated with the most severe disease rating (R5). *Rhizopus* spp. (11A, B, C) was associated with the healthiest plants (R1).

Discussion

The low incidences of soilborne fungal pathogens observed in this study were initially discouraging, as their presence was essential to determine the relationship between foliar diseases and soilborne diseases of peanut. However, the lack of major pathogens did provide the opportunity to observe how the incidence of minor pathogens and non-pathogens might change over time in their absence. It also provided the opportunity to study how minor pathogens alone might affect the health of the crop.

Two factors separate this study from those to evaluate the effect of fungicides and cultivars on the incidence of soilborne fungi associated with peanut (Chapters 5 and 6). First, in the previous two studies, efforts were taken to control foliar diseases for all the plants in the study. One objective in this project was to produce different levels of foliar disease to see if this had any affect on the severity of soilborne disease. The second difference between this study and the studies from Quincy and Santa Rosa County was the low incidence of soilborne pathogens. *C. parasiticum, S. rolfsii*, and *Pythium* spp. were not isolated from this field. Apparently, the rotation with bahiagrass had been

Figure 7-18. Simple correspondence analysis from 1998 to establish the relationship between the health rating given to each sampled plant and the incidence of specific fungi isolated from three treatments to control foliar diseases. The variables R1 through R5 represent the five health ratings given to the plant from which fungi were isolated. A symptomless plant is represented by R1. Plants with discoloration or restricted lesions are represented by R2. The plants with expanding lesions and slight wilt are represented by R3. The plants with more substantial wilt and some necrotic tissue are represented by R4. The plants with severe wilt and necrosis to the point of death are represented by R5. The letters A, B, and C represent the rate of chlorothalonil applied to the peanut plants from which the isolations were made. The control is represented by A, the middle rate by B, and high rate by C. The fungi are represented as follows: *Aspergillus flavus* (1), *Aspergillus niger* (2), *Cylindrocladium parasiticum* (3), *Fusarium* spp. (4), *Lasiodiplodia theobromae* (5), *Macrophomina phaseolina* (6), *Neocosmospora vasinfecta* (7), *Phomopsis* sp. (8), *Pythium* spp. (9), *Rhizoctonia solani* (10), *Rhizopus* spp. (11), *Sclerotium rolfsii* (12), *Trichoderma* spp. (13), and *Zygorhynchus* sp. (14). Units on the horizontal and vertical axes were not defined when the results from correspondence analysis were plotted.


R1
R2
R3
R4
R5
10A
11C
5C
14C
8C
11A
11B
14B
1B
7B
2B
13B
4B
10B
8B
5B
6B
6A
10C
4A
2C
7A
1A
1C
7C
4C
2A, 6C, 13A, 13C
8A
5A
14A
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6

effective to reduce the inoculum density of *S. rolfsii* from levels of previous years. Also, the incidence of the pathogen *L. theobromae* was low.

There are several different ways in which the level of control of foliar diseases of peanut might affect the severity of important soilborne diseases such as Cylindrocladium black rot and southern stem blight. For example, the incidence of southern stem blight increased when defoliating pests, such as the leaf spot pathogens, were controlled, as the maintenance of the foliar canopy was enhanced (154). In bean, *Phaseolus vulagaris*, the susceptibility of different cultivars to white mold caused by *Sclerotinia sclerotiorum* was related to their specific growth habits (152). The most susceptible varieties produced foliar canopies that were denser than were the canopies of resistant varieties. The severity of Cylindrocladium black rot is enhanced by cooler temperatures (156). Defoliation by leaf spot pathogens would reduce the density of the canopy and perhaps increase the soil temperature in the pegging zone from what it would have been. This increase in temperature could reduce infection by *C. parasiticum*.

However, a limited amount of defoliation may actually increase the severity of southern stem blight. Sclerotia from *S. rolfsii* were induced to germinate in the presence of dried peanut leaves that had been remoistened (21). The researchers believed that volatile compounds that were emitted from these leaves, but not from green leaves or from vigorously growing stems, stimulated the germination of the sclerotia and initiated epidemics of southern stem blight. Natural defoliation occurs as the plants approach maturity or during

times of drought. The degradation of the defoliated leaves could induce germination of the sclerotia (21).

In this study, the temporal succession of growth stages of the host was not different among the three fungicide programs (Table 7-1). Thus, even though the plants that were not sprayed with chlorothalonil were severely defoliated at the end of the season, this did not affect the growth stages present on a sampling date. Likewise, the development of the foliar canopy was similar among the three treatments. As in the preceding studies in Quincy and Santa Rosa County, the closure of the canopy occurred approximately 80 days after planting. However, leaf-density was certainly greater in the plots sprayed with chlorothalonil than in the control. This difference in canopy density may have been an important factor had *S. rolfsii* or *C. parasiticum* been present in the field. The defoliation that occurred in the control plots did not affect the incidences of the fungi that were evaluated.

As in the surveys from 1995 and 1996 and the previous field studies, the incidences of most of the fungi that were evaluated during this study increased as the season progressed (Figures 7-5 to 7-15). Perhaps the most surprising aspects of the general incidence of these fungi were the abundance of both *N. vasinfecta* (Figure 7-7) and *Trichoderma* spp. (Figure 7-11). Both of these fungi were commonly isolated in the commercial fields evaluated in 1995, 1996, 1998, and 1999, but the high magnitude of this incidence was unusual and possibly the result of the long rotation with bahiagrass.

Control of foliar disease of peanut using different rates of chlorothalonil did not significantly reduce or increase the incidence of any of the fungi evaluated in this study. Had *S. rolfsii* or *C. parasiticum* been present in this field, their incidence may have been affected due to a relationship with the development of the foliar canopy.

Without the presence of important soilborne pathogens, the disease severity associated with the different rates of fungicide was low. Soilborne disease in plots treated with the mid-rate of chlorothalonil were slightly higher than in the control or in those plots treated with the high rate of fungicide. The difference in severity between the plots treated with chlorothalonil did not differ by one standard deviation and was probably not significant. However, the use of various rates of chlorothalonil helped to increase yield (Figure 7-2) and to reduce foliar disease (Figure 7-3).

From the results of simple correspondence analysis presented in Figure 7-16, most of the fungi had a general distribution over the season for all treatments; these included *A. flavus*, *A. niger*, *Fusarium* spp., *M. phaseolina*, *N. vasinfecta*, *Rhizopus* spp., and *Trichoderma* sp. In this study, the distinctions between the foundational and secondary stages of development were unclear. Certainly *Fusarium* spp., *A. niger*, *M. phaseolina*, *N. vasinfecta*, and *Trichoderma* sp. would be considered to be a part of the earliest foundational stage. The others, including *R. solani*, became more abundant soon after the initial sampling dates and thus could be considered part of either the foundational or the secondary stage of development.

Phomopsis sp. and *L. theobromae* were two fungi consistently associated with the latest growth stages and with the pegs. *Phomopsis* sp. was an important member of the peg community, while *L. theobromae* could be placed with either the tertiary stage of development of the general community or in the peg community. In the general surveys in 1995 and 1996, *L. theobromae* was associated with other tissues in addition to the pegs. However, in the three studies conducted beginning in 1998, this pathogen had been primarily associated with the pegs.

Disease Ratings and the Incidences of Soilborne Fungi

The plants in this study were generally unaffected by soilborne disease, as would be expected given the lack of soilborne pathogens. The fungi associated with greatest disease severity were *Phomopsis* sp. and *L. theobromae* from the plots that received the low rate of fungicide and perhaps from the control plots. *Lasiodiplodia theobromae* appeared to be the pathogen responsible for the severe symptoms. Because *Phomopsis* sp. colonized peanut later in the season, as does *L. theobromae*, *Phomopsis* sp. tended to be associated with a higher percentage of diseased plants. For similar reasons, though *Rhizopus* spp. was associated with the healthiest plants, it probably did not protect the peanut plant from disease. Rather, *Rhizopus* spp. occurred earlier in the season when a larger proportion of the plants were healthy.

Conclusions

The use of two rates of chlorothalonil reduced the severity of peanut rust and increased yields in a study conducted in Suwannee County, Florida. Control

of the severity of foliar disease did not affect the development of the soilborne communities of fungi, but important pathogens such as *C. parasiticum* and *S. rolfsii* did not occur. Control of foliar disease did not affect the size of the canopy, but it affected the amount of defoliation and the leaf-density of the canopy.

In the absence of most major soilborne pathogens, the plants in the study were generally free of soilborne disease. However, *L. theobromae* was associated with some severe symptoms. Weak pathogens, such as *Fusarium* sp. and *N. vasinfecta*, did not produce symptoms of disease.

CHAPTER 8
SUMMARY

Forty-eight genera of fungi were isolated from those parts of the peanut plant that develop within the soil. These parts were: hypocotyls, roots, pegs, and pods. Many of these fungi were not identified beyond the generic level and it is probable that multiple species of genera such as *Fusarium* spp. and *Penicillium* spp. were associated with peanut in Florida.

Some of the fungi, such as *Fusarium* spp., *Penicillium* spp., *Trichoderma* spp., *Neocosmospora vasinfecta*, and *Macrophomina phaseolina,* are ubiquitous in peanut fields across the state and are abundant in most fields. Other fungi, such as *Rhizoctonia solani*, *Rhizopus* spp., *Mucor* spp., *Aspergillus flavus*, *Aspergillus niger, Curvularia* spp., and *Alternaria* spp., were also found in most fields around the state, but were less frequently isolated than fungi listed above. Finally, many fungi are less common across the state and are isolated from fewer plants within the fields in which they are found. Such fungi include *Sclerotium rolfsii, Leptosphaerulina* sp., *Cylindrocladium parasiticum*, and *Epicoccum* sp. Other fungi, such as *Robillardia* sp., *Pyrenochaeta* sp., and *Calcarisporium* sp. were only isolated once or twice during both 1995 and 1996.

Of the fungi that were not isolated from all of the fields surveyed in 1995 and 1996, some were more common in specific regions of the state and less common in others. For example, *C. parasiticum* was more common in the

Panhandle of Florida, while a *sterile white basidiomycete*, *Torula* sp., and *Zygorhynchus* sp. were more common in peninsular Florida.

Fortunately for growers, the majority of the soilborne fungi that colonize the peanut plant in Florida are not pathogens. Pathogenicity tests of the common fungi that were isolated in this study did not identify any new pathogens, but did confirm that *Fusarium* spp. and *N. vasinfecta* can be pathogenic, especially to wounded seedlings. *Macrophomina phaseolina*, *Cylindrocladiella* sp., and a sterile white basidiomycete have been associated with diseases of peanut, but did not cause symptoms in this study. Based on inoculations into wounded plants, *A. niger, C. parasiticum, S. rolfsii*, and *Lasiodiplodia theobromae* were capable to kill plants rapidly. *Cylindrocladium parasiticum* and *L. theobromae* killed wounded plants of all ages, though there were differences in the virulence of the isolates of *C. parasiticum*. *Sclerotium rolfsii* was pathogenic to plants of all ages, while *A. niger* was more virulent on seedlings. Isolates of *R. solani* did not produce severe symptoms of disease on plants of any age. Disease symptoms were more severe in peanut plants inoculated with *C. parasiticum* and grown at lower temperatures. Symptoms associated with *S. rolfsii* were more severe at warmer temperatures. Symptoms associated with *L. theobromae* were typically severe at all temperatures.

Some of the fungi that were isolated from peanut were antagonistic to pathogens when grown in competition on plates of agar. *Trichoderma* spp. outcompeted and overgrew colonies of *R. solani*, *S. rolfsii*, and *M. phaseolina*. Exudates of *Chaetomium* sp. inhibited the growth of *R. solani* and *M. phaseolina*,

but had only a limited affect on *S. rolfsii*. Colonies of *M. phaseolina* were especially sensitive to the growth of other fungi and were inhibited by several different fungi.

The incidences of some soilborne fungi were significantly correlated with the incidences of other fungi, production practices used by the growers, and characteristics of individual fields, such as populations of plant parasitic nematodes and concentrations of nutrients. For example, the incidences of *L. theobromae*, *C. parasiticum*, and *Phomopsis* sp. were positively correlated with each other whereas the incidences of *C. parasiticum* and *L. theobromae* were negatively correlated with the incidence of *Trichoderma* spp. Planting dates, crop rotation, concentrations of calcium, magnesium, potassium, phosphorus, and hydronium ions (pH) in the soil, and populations of the plant parasitic nematodes *Meloidogyne* spp. and *Pratylenchus* spp. were all weakly correlated with changes in the incidences of some fungi.

The incidences of most of the soilborne fungi that colonized peanut in Florida changed in non-random patterns over time. The most common trend for these changes was an increase in incidence to some maximum during the season and then remain fairly constant for the remainder of the season. However, some fungi, such as *Phoma* sp., and *Alternaria* sp., typically reached a peak in incidence and then declined over the remainder of the season. The diversity of fungi that colonize peanut is lowest during the seedling stage and increased as the plant matured.

Soilborne fungi may be more disproportionately associated with specific parts of the host than with others. For example, *N. vasinfecta* was closely associated with the roots; *Phomopsis* sp. was closely associated with the pegs; and *Rhizopus* spp. was isolated most frequently from hypocotyls and the roots. Other fungi, such as *Fusarium* spp. and *Trichoderma* spp. were more generally associated with all four regions.

Close observations of the incidences of the fungi as they related to the progressive growth stages of the peanut plant led to the realization that different fungi shared similar patterns of development and could be grouped logically together based upon these similarities. Furthermore, two communities of soilborne fungi, a general community and a peg community, were defined by these similarities and by preferential colonization of host tissues.

The largest community of soilborne fungi, the general community, was quite dynamic and progressed through three stages of development that were related to the growth of the peanut host. The stages in the development of this fungal community did not represent distinct seral communities, primarily because the emergence of new fungal taxa to prominence was not coupled with the disappearance of earlier taxa.

The earliest stage in the development of this fungal community was labeled "foundational" and it occurred during the seedling stage of the host development. Fungi that were frequently isolated during this stage included *Fusarium* spp., *A. niger*, and *Trichoderma* spp. These fungi tended to become established in the plant very early, they tended to reach high incidences during

the season, and to colonize all parts of the parts of the plant below the soil. These fungi were quite common throughout the state.

The next stage in the development of the general community of soilborne fungi was labeled "secondary." Distinctions between the foundational and secondary stages may be blurred in individual fields. However they were soundly based on the repeated observations that fungi most often associated with the youngest seedlings were less diverse than those associated with later vegetative stages of host development. The secondary stage in the development of the general community occurred with the later vegetative stages and early reproductive stages of the host. Fungi that reached high incidences and were more commonly associated with the roots and pegs or pods than they were with the hypocotyls characterized the secondary stage. Fungi that typically became established during this time included *R. solani, Mucor* spp., *N. vasinfecta*, and *M. phaseolina*.

The tertiary stage in the development of the general community of fungi and the second distinctive community, the "peg" community, both emerged under the same conditions. They were both associated with changes that occurred later in the growing season and included the development of the pods, maturation of the seeds, and the full closure of the foliar canopy. Development of the foliar canopy appeared to be associated with slightly cooler temperatures in the pegging zone and within the foliage and also an increased relative humidity within the canopy. These changes to the microclimate that affected soilborne fungi may have been more conducive for infection and disease

development than the warmer temperature and low relative humidity measured before the canopy developed.

Fungi that became more prominent during the tertiary stage were often associated with the roots and the pegs or pods. Their incidence was very limited earlier in the season, but they increased quickly when conditions were favorable. Fungi that were considered important during the tertiary stage included *C. parasiticum*, *Pythium* spp., and *L. theobromae*. There was also evidence that *S. rolfsii* was a part of this stage, though it could be placed in the peg-community as well.

The peg-community was distinct from the general community of soilborne fungi associated with peanut. Those fungi that were included in the peg-community were isolated with greater frequency from the pegs than from any other part of the plant and belonged to genera known to contain foliar pathogens of peanut. This may occur because the pegs originated above the surface of the soil and grew down into the soil. Fungi included in the peg community were *Phomopsis* sp., *Leptosphaerulina* spp., *Phoma* sp., *Alternaria* sp., and *Curvularia* sp. The incidences of *S. rolfsii* and *L. theobromae* were similar enough to these fungi that they should also be considered at least associated with the peg-community.

Two other groups of fungi belonged to the large, general community of soilborne fungi, but they could not be linked to a single stage of development. Fungi such as *Rhizopus* spp., *A. flavus*, and *Cunninghamella* sp. belonged to a group of fungi that may never reach a large incidence, but that were associated

with all of the developmental stages and also may have been disproportionately associated with the hypocotyls. An "ephemeral" group contained those fungi found with such low incidence that it was difficult to determine how their incidence changed over time. Fungi included in this group were *Colletotrichum* sp., *Gliocladium* sp., *Gleosporium* sp., and *Cladosporium* sp.

The foundational stage in the development of the community of soilborne fungi appears to be based upon the ability of some fungi, such as *Fusarium* spp., to colonize the new seedling rapidly. The emergence of the secondary stage was, at least in part, the result of the growth of the root system and the emergence of the pods and pegs. The emergence of the tertiary stage and the peg community appeared to be related to the maturation of the pegs and pods and changes in microclimates associated with the foliar canopy.

Differences in yields and the severity of soilborne diseases were associated with the use of different fungicides and different cultivars, though they did not appear to have much affect on the development of the fungal communities. The severity of soilborne disease was less in Florida MDR 98 and Georgia Green than it was in Florunner. The incidences of *S. rolfsii* were not different among varieties, but in 1998 the colonization by *C. parasiticum* was delayed in Florida MDR 98 and Georgia Green when compared to Florunner. The severity of soilborne disease was less in plots treated with tebuconazole or flutolanil than in those treated with benomyl or only chlorothalonil. *Sclerotium rolfsii* was isolated earlier in the control plots and in plots treated with benomyl.

The incidence of *S. rolfsii* was reduced in those plants sprayed with flutolanil or tebuconazole on at least one sampling date in 1998 and in 1999.

The severity of peanut rust caused by *Puccinia arachidis* decreased yields, but did not affect the composition of the communities of soilborne fungi. This study was conducted in a field in which the important pathogens *Pythium* spp., *C. parasiticum*, and *S. rolfsii* did not occur. The effect of control of foliar diseases on soilborne disease was not evaluated in fields with more severe incidences of soilborne diseases.

REFERENCES

1. Abu-Gharbieh, W., Varney, E. H., Jenkins, W. R. 1962. Relationships of meadow nematodes to Verticillium wilt of strawberries. (Abstr.) Phytopathology 52:921.

2. Ahmed, E. M., and Young, C. T. 1982. Composition, quality, and flavor of peanuts. Pages 655-688 *in:* Peanut Science and Technology. H. E. Pattee and C. T. Young, eds. American Peanut Research and Education Society, Inc., Yoakum, TX.

3. Alexopoulos, C. J., Mims, C. W., and Blackwell, M. 1996. Introductory Mycology, 4th ed. John Wiley & Sons, Inc., New York. 868 pp.

4. Anonymous. 1982. The annual report of the peanut collaborative research support program (CRSP) 1982. United States Agency for International Development Department of State. Grant No. DAN-4048-G-SS-2065-00.

5. Anonymous. 1998. Peanut and products: Supply and distribution. United States Department of Agriculture Foreign Agricultural Service. www.fas.usda.gov/oilseeds/circular/1998/.

6. Anonymous. 1998. Florida agricultural statistics: field crop summary 1998. Florida Agricultural Statistics Service, Orlando, FL.

7. Anonymous. 1999. Crop production. USDA National Agricultural Statistics Service. Washington DC. Cr Pr 2-2 (11-99)a.

8. Anonymous. 1999. Peanut types and production. American Peanut Council. Alexandria, VA. www.peanutsusa.com/what/types.html.

9. Backman, P. A., and Brenneman, T. B. 1997. Stem rot. Pages 36-37 *in:* Compendium of Peanut Diseases, 2nd ed. N. Kokalis-Burelle, D. M. Porter, R. Rodriguez-Kabana, D. H. Smith, and P. Subrahmanyam, eds. American Phytopathological Society, St. Paul, MN.

10. Backman, P. A., Rodriguez-Kabana, R., and Williams, J. C. 1975. The effect of peanut leafspot fungicides on the non-target pathogen, *Sclerotium rolfsii*. Phytopathology 65:773-776.

11. Bacon, C. W., and Hinton, D. M. 1996. Symptomless endophytic colonization of maize by *Fusarium moniliforme*. Can. J. Bot. 74:1195-1202.

12. Baird, R. E., Brenneman, T. B., Bell, D.K., Culbreath, A., and Mullinix, B. G. 1993. The peanut shell mycobiota of detached vs. mechanically harvested pods either treated or not treated with flutolanil. Plant Dis. 77:405-408.

13. Baird, R. E., Brenneman, T. B., Bell, D. K., Sumner, D. R., Minton, N. A., Mullinix, B. J., and Peery, A. B. 1995. Influence of crop rotation and flutolanil on the diversity of fungi on peanut shells. Phytoprotection 76:101-113.

14. Baird, R. E., Brenneman, T. B., Mullinix, B. G., Bell, D. K., Culbreath, A. K., and Moore, J. D. 1993. The effects of chemical treatment, harvest date, and specific isolation media on the peanut shell mycobiota of two peanut cultivars. Plant Dis. 77:736-741.

15. Balducci, A. J., and McGee, D. C. 1987. Environmental factors influencing infection of soybean seeds by *Phomopsis* and *Diaporthe* species during seed maturation. Plant Dis. 71:209-212.

16. Barnes, J. S., and Csinos, A. S. 1990. Effects of fungicides, cultivars, irrigation, and environment on Rhizoctonia limb rot of peanut. Plant Dis. 74:671-676.

17. Bell, D. K., Minton, N. A., and Doupnik, Jr., B. 1971. Effects of *Meloidogyne arenaria, Aspergillus flavus*, and curing time on infection of peanut pods by *Aspergillus flavus*. Phytopathology 61:1038-1039.

18. Bell, D. K., and Sumner, D. R. 1984. Ecology of a sterile white basidiomycete in corn, peanuts, soybean, and snap bean field microplots. Plant Dis. 68:18-22.

19. Bell, D. K., and Sumner, D. R. 1984. Unharvested peanut pods as a potential source of inoculum of soilborne plant pathogens. Plant Dis. 68:1039-1042.

20. Beute, M. K. 1997. *Pythium* disease. Pages 27-30 *in:* Compendium of Peanut Diseases, 2nd ed. N. Kokalis-Burelle, D. M. Porter, R. Rodriguez-Kabana, D. H. Smith, and P. Subrahmanyam, eds. American Phytopathological Society, St. Paul, MN.

21. Beute, M. K. and Rodriguez-Kabana, R. 1979. Effect of volatile compounds from remoistened plant tissues on germination and growth of sclerotia of *Sclerotium rolfsii*. Phytopathology 69:801-805.

22. Bissett, J., and Parkinson, D. 1978. Fungal community structure in alpine soils. Can. J. Bot. 57:1630-1641.

23. Black, M. C., and Beute, M. K. 1984. Effects of rotations with susceptible and resistant peanuts, soybeans, and corn on inoculum efficiency of *Cylindrocladium crotalariae* on peanuts. Phytopathology 68:401-405.

24. Black, M. C. and Beute, M. K. 1984. Different ratios of general: specific virulence variance among isolates of *Cylindrocladium crotalariae* from different peanut genotypes. Plant Dis. 74:941-945.

25. Boote, K .J. 1982. Growth stages of peanut (*Arachis hypogaea* L.). Peanut Sci. 9:35-40.

26. Boswell, T. E., and Starr, J. L. 1997. Root-lesion nematodes. Pages 48-50 *in:* Compendium of Peanut Diseases, 2nd ed. N. Kokalis-Burelle, D. M. Porter, R. Rodriguez-Kabana, D. H. Smith, and P. Subrahmanyam, eds. American Phytopathological Society, St. Paul, MN.

27. Bowen, K. L., Hagan, A. K., and Weeks, J. R. 1996. Soil-borne pests in growers' fields with different cropping histories in Alabama. Peanut Sci. 23:36-42.

28. Branch, W. D., and Csinos, A. S. 1987. Evaluation of peanut cultivars for resistance to field infection by *Sclerotium rolfsii*. Plant Dis. 71:268-270.

29. Brenneman, T. B. 1991. Effects of three different epidemics of southern stem rot on pod yields of Florunner and Southern Runner. Phytopathology (Abstr.) 81:810.

30. Boyle, L. W. 1953. Heat canker: a primary phase of collar rot of peanuts. Phytopathology 43:571-576.

31. Brenneman, T. B. 1997. *Rhizoctonia* diseases. Pages 30-31 *in:* Compendium of Peanut Diseases, 2nd ed. N. Kokalis-Burelle, D. M. Porter, R. Rodriguez-Kabana, D. H. Smith, and P. Subrahmanyam, eds. American Phytopathological Society, St. Paul, MN.

32. Brenneman, T. B., and Culbreath, A. K. 1994. Utilizing a sterol demethylation inhibiting fungicide in an advisory program to manage foliar and soilborne pathogens of peanut. Plant Dis. 78:866-872.

33. Brenneman, T. B., Murphy, A. P., and Csinos, A. S. 1991. Activity of tebuconazole on *Sclerotium rolfsii* and *Rhizoctonia solani*, two soilborne pathogens of peanut. Plant Dis. 75:744-747.

34. Brenneman, T. B., Wilson, D. M., and Beaver, R. W. 1993. Effects of diniconazole on Aspergillus populations and aflatoxin formation in peanut under irrigated and non-irrigated conditions. Plant Dis. 77:608-612.

35. Brown, A. E. 1987. Activity of glucanases of *Zygorhynchus moelleri* in relation to antagonism against some soil-borne plant pathogenic fungi. J. Phytopathol. 120:298-309.

36. Brown, A. E. 1988. Supression by *Zygorhynchus moelleri* of growth and sclerotium productivity by *Rhizoctonia solani* and *Sclerotinia sclerotiorum*. J. Phytopathol. 123:22-226.

37. Brown, A. E., and Surgeoner, R. 1991. Enhancement of plant growth by *Zygorhynchus moelleri*. Ann. Appl. Biol. 118:39-46.

38. Campbell, C. L. 1982. Fungi associated with tap roots of ladino clover in North Carolina. (Abstr.) Phytopathology 72:356.

39. Cannon, P. F., and Hawksworth, D. L. 1984. A revision of the genus *Neocosmospora* (Hypocreales). Trans. Br. Mycol. Soc. 82:673-688.

40. Carling, D. E., and Leiner, R. H. 1990. Effect of temperature on virulence of *Rhizoctonia solani* and other *Rhizoctonia* on potato. Phytopathology 80:930-934.

41. Carling, D. E., Roncadori, R. W., and Hussey, R. S. 1996. Interactions of arbuscular mycorrhizae, *Meloidogyne arenaria*, and phosphorus fertilization on peanut. Mycorrhiza 6:9-13.

42. Carlsson, U., Elmquist, T., Wennstrom, A., and Ericson, L. 1990. Infection by pathogens and population age of host plants. Journal of Ecology 78:1094-1105.

43. Chet, I., and Baker, R. 1980. Induction of suppressiveness to *Rhizoctonia solani* in soil. Phytopathology 70:994-998.

44. Cobb, W. Y., and Johnson, B. R. 1973. Physiochemical properties of peanuts. Pages 209-264 *in*: Peanuts: Cultures and Uses. American Peanut Research and Education Association, Stillwater, OK.

45. Coffelt, T. A., and Simpson, C. E. 1997. Origin of the peanut. Page 2 *in:* Compendium of Peanut Diseases, 2nd ed. N. Kokalis-Burelle, D.M. Porter, R. Rodriguez-Kabana, D.H. Smith, and P. Subrahmanyam, eds. American Phytopathological Society, St. Paul, MN.

46. Cole, D. L., and Liddell, C. 1997. Web blotch. Pages 39-40 *in:* Compendium of Peanut Diseases, 2nd ed. N. Kokalis-Burelle, D. M. Porter, R. Rodriguez-Kabana, D. H. Smith, and P. Subrahmanyam, eds. American Phytopathological Society, St. Paul, MN.

47. Coley-Smith, J. R., and Cooke, R. C. 1971. Survival and germination of fungal sclerotia. *in:* Ann. Rev. Phytopathol. 9:65-92.

48. Connell, J. O., and Slatyer, R. O. 1977. Mechanisms of succession in natural communities and their role in community stability and organization. Am. Nat. 111:1119-1144.

49. Cox, F. R., and Sholar, J. R. 1995. Site selection, land preparation, and management of soil fertility. Pages 7-10 *in:* Peanut Health Management. H. A. Melouk and F. M. Shokes, eds. American Phytopathological Society, St. Paul, MN.

50. Cox, F. R., Adams, F., and Tucker, B. B. 1982. Liming, fertilization, and mineral nutrition. Pages 139-163 *in:* Peanut Science and Technology. H. E. Pattee and C. T. Young, eds. American Peanut Research and Education Society, Inc., Yoakum, TX.

51. Crous, P. W., Phillips, A. J. L., and Wingfield, M. J. 1993. New records of *Cylindrocladium* and *Cylindrocladiella* spp. in South Africa. Plant Pathology 42:302-305.

52. Csinos, A. S. 1985. Nontarget activity of chlorpyrifos and hydrolysis products on *Sclerotium rolfsii*. Plant Dis. 69:254-256.

53. Csinos, A. S., Bell, D. K., Minton, M. A., and Wells, H. D. 1983. Evaluation of *Trichoderma* sp., fungicides, and chemical combinations for control of southern stem rot on peanuts. Peanut Sci. 10: 75-79.

54. Csinos, A. S., and Bell, D. K. 1989. Pathology and nutrition in the peanut pod rot complex. *in:* Soilborne Plant Pathogens: Management of Disease with Macro-and Microelements. Engelhard, A. W., ed. APS Press, ST. Paul, MN.

55. Csinos, A. S., and Bell, D. K. 1997. Peanut pod rot complex. Pages 23-24 *in:* Compendium of Peanut Diseases, 2nd ed. N. Kokalis-Burelle, D. M. Porter, R. Rodriguez-Kabana, D. H. Smith, and P. Subrahmanyam, eds. American Phytopathological Society, St. Paul, MN.

56. Csinos, A. S., and Gaines, T. P. 1986. Peanut pod rot complex: a geocarposphere nutrient imbalance. Plant Dis. 70:525-529.

57. Csinos, A. S., Gaines, T. P., and Walker, M. E. 1984. Involvement of nutrition and fungi in the peanut pod rot complex. Plant Dis. 68:61-65.

58. Culbreath, A. K., Beute, M. K., and Campbell, C. L. 1991. Spatial and temporal aspects of epidemics of Cylindrocladium black rot in resistant and susceptible peanut genotypes. Phytopathology 81:144-150.

59. Culbreath, A. K., Beute, M. K., Shew, B. B., and Barker, K. R. 1992. Effects of *Meloidogyne hapla* and *M. arenaria* on black rot severity in new Cylindrocladium-resistant peanut genotypes. Plant Dis. 76:352-357.

60. Culbreath, A. K., Minton, N. A., Brenneman, T. B., and Mullinix, B. G. 1992. Response of Florunner and Southern Runner cultivars to chemical management of late leaf spot, southern stem rot, and nematodes. Plant Dis. 76:1199-1203.

61. Cullen, D., and Andrews, J. H. 1984. Evidence for the role of antibiosis in the antagonism of *Chaetomium globosum* to the apple scab pathogen, *Venturia inaequalis*. Can. J. Bot. 62:1819-1823.

62. Dawson, W. A., and Bateman, G. L. 1998. Fungal communities on roots and shoot bases of winter barley and winter wheat during crop development. Abstr. 2.7.9. http://www.bspp.org.uk/icpp98/abstracts/.

63. De Cal, A., and Melgarejo, P. 1992. Interactions of pesticides and mycoflora of peach twigs. Mycol. Res. 96:1105-1113.

64. Diomande, M., and Beute, M. K. 1981. Effects of *Meloidogyne hapla* and *Macroposthonia ornata* on Cylindrocladium black rot of peanut. Phytopathology 71:491-496.

65. Dix, N. J. 1964. Colonization and decay of bean roots. Trans. Brit. Mycol. Soc. 47:285-292.

66. Engelkes, C. A., and Windels, C. E. 1994. Relationship of plant age, cultivar, and isolate of Rhizoctonia AG-2-2 to sugar beet root and crown rot. Plant Dis. 78:685-689.

67. Farr, D. F., Bills, G. F., Chamuris, G. P., and Rossman, A. Y. 1989. Fungi on Plants and Plant Products in the United States. American Phytopathological Society Press, St. Paul, MN. 1252 pp.

68. Filonow, A. B., Melouk, H. A., Martin, M., and Sherwood, J. 1988. Effect of calcium sulfate on pod rot of peanut. Plant Dis. 72:589-593.

69. Forbes, G. A., and Davet, P. 1991. Association of soybean root mycoflora with root nodulation, root necrosis, and plant fresh weight. Ann. Appl. Biol. 118:533-541.

70. Franke, M. D., and Brenneman, T. B. 1998. Sensitivity of isolates of *Sclerotium rolfsii* from peanut in Georgia to selected fungicides. Plant Dis. 82:578-583.

71. Frank, Z. R., and Ben-Yephet, Y. 1997. *Fusarium* diseases. Pages 20-22 *in:* Compendium of Peanut Diseases, 2nd ed. N. Kokalis-Burelle, D. M. Porter, R. Rodriguez-Kabana, D. H. Smith, and P. Subrahmanyam, eds. American Phytopathological Society, St. Paul, MN.

72. Fritz, V. A., Honma, S., and Widders, I. 1988. Effects of petiole calcium, petiole location, and plant age on the incidence and progression of soft rot in Chinese cabbage. J. Amer. Soc. Hort. Sci. 113:56-61.

73. Garcia, R., and Mitchell, D. J. 1975. Synergistic interaction of *Pythium myriotylum* with *Fusarium solani* and *Meloidogyne arenaria* in pod rot of peanut. Phytopathology 65:832-833.

74. Garcia, R., and Mitchell, D. J. 1975. Interactions of *Pythium myriotylum* with several fungi in peanut pod rot. Phytopathology 65:1375-1381.

75. Garren, K. H. 1966. Peanut (groundnut) microfloras and pathogenisis in peanut pod rot. Phytopath Z. 55:359-367.

76. Garren, K. H. 1970. *Rhizoctonia solani* versus *Pythium myriotylum* as pathogens of peanut pod breakdown. Plant Dis. Rptr. 54:840-843.

77. Garrett, S. D. 1960. Biology of Root-Infecting Fungi. Cambridge Univ. Press, Cambridge. 294 pp.

78. Garrett, S. D. 1970. Pathogenic Root-Infecting Fungi. Cambridge Univ. Press, Cambridge. 291 pp.

79. Gascho, G. J., and Davis, J. G. 1995. Soil fertility and plant nutrition. pp. 383-418 *in*: Advances in Peanut Science. H. E. Pattee and H. T. Stalker, eds. American Peanut Research and Education Society, Inc., Stillwater, OK.

80. Gregory, W. C., Smith, B. W., and Yarbrough, J. A. 1951. Morphology, genetics and breeding. Pages 28-88 *in*: The Peanut: The Unpredictable Legume. The National Fertilizer Association, Washington, D. C.

81. Gregory, W. C., Gregory, M.P, Krapovikas, A., Smith, B. W., and Yarbrough, J. A. 1973. Structure and genetic resources of peanuts. Pages 47-134 *in*: Peanuts: Cultures and Uses. American Peanut Research and Education Association, Inc., Stillwater, OK.

82. Griffin, G. J., and Garren, K. H. 1976. Colonization of aerial peanut pegs by *Aspergillus flavus* and A. niger-group fungi under field conditions. Phytopathology 66:1161-1162.

83. Griffin, G. J., Garren, K. H., and Taylor, J. D. 1981. Influence of crop rotation and minimum tillage on the population of *Aspergillus flavus* group in peanut field soil. Plant Dis. 65:898-900.

84. Gwinn, K. D., Stelzig, D. A., and Brooks, J. L. 1987. Effects of corn plant age and cultivar on resistance to *Cercospora zea-maydis* and sensitivity to cercosporin. Plant Dis. 71:603-606.

85. Hammons, H. D. 1982. Origin and early history of the peanut. Pages 1-20 *in:* Peanut Science and Technology. H. E. Pattee and C. T. Young, eds. American Peanut Research and Education Society, Inc., Yoakum, TX.

86. Hanlin, R. T. 1973. The distribution of peanut fungi in the southeastern United States. Mycopathologia et Mycologia Applicata 49:227-241.

87. Harley, J. L., and Waid, J. S. 1955. A method of studying active mycelia on living roots and other surfaces in the soil. Trans. Brit. Mycol. Soc. 38:104-118.

88. Harris, J. R., and Moen, R. 1985. Replacement of *Rhizoctonia solani* on wheat seedlings by a succession of root-rot fungi. Trans. Br. Mycol. Soc. 84:11-20.

89. Hasan, A. 1988. Interaction between *Pratylenchus coffeae* and *Pythium aphanidermatum* and/or *Rhizoctonia solani* on Chrysanthemum. J. Phytopathology 123:227-232.

90. Hastings, R . J., and Bosher, J. E. 1938. A study of the pathogenicity of the meadow nematode and the associated fungus *Cylindrocarpon radicicola* Wr. Can. J. Research, Sec. C, 16:225-229.

91. Hau, F. C., Campbell, C. L., and Beute, M. K. 1982. Inoculum distribution and sampling methods for *Cylindrocladium crotalariae* in a peanut field. Plant Dis. 66:568-571.

92. Hawksworth, D. L., Kirk, P. M., Sutton, B. C., and Pegler, D. N., eds. 1995. Ainsworth and Bisby's Dictionary of the Fungi, 8th ed. International

Mycological Institute, Cab International. University Press, Cambridge. 616 pp.

93. Henning, R .J., Allison, A. H., and Tripp, L. D. 1982. Cultural practices. Pages 123-138 *in:* Peanut Science and Technology. H. E. Pattee and C. T. Young, eds. American Peanut Research and Education Society, Inc., Yoakum, TX.

94. Holdeman, Q. L. 1954. Nematodes as possible members of disease complexes involving other plant pathogens. Plant Dis. Reptr. Suppl. 227:77-79.

95. Hollowell, J. E., Shew, B. B., and Beute, M. K. 1997. Peanut pod rotting incidence and causal pathogens. Phytopathology 87 (Abstr.):S112.

96. Horn, B. W., and Pitt, J. I. 1997. Yellow mold and aflatoxin. Pages 40-42 *in:* Compendium of Peanut Diseases, 2nd ed. N. Kokalis-Burelle, D. M. Porter, R. Rodriguez-Kabana, D. H. Smith, and P. Subrahmanyam, eds. American Phytopathological Society, St. Paul, MN.

97. Hotchkiss, M. W., and Baxter, L. W. 1982. Fungi associated with pod and peg rot of peanut (*Arachis hypogaea* L.) in South Carolina. (Abstr.) Phytopathology 72:358.

98. Huisman, O. C. 1982. Interrelations of root growth dynamics to epidemiology of root-invading fungi. *in*: Ann. Rev. Phytopathol. 20:303-327.

99. Jackson, C. R. 1968. A field study of fungal associations on peanut fruit. Research Bulletin 26. University of Georgia College of Agriculture Experiment Stations, Athens, GA. 29 pp.

100. Jacobi, J. C., and Backman, P. A. 1991. Effects of tebuconazole on seed quality and fungal colonization of two cultivars of peanut. Phytopathology (Abstr.) 81:812.

101. Jeffrey, K. K., Lipps, P. E., and Herr, L. J. 1984. Effects of isolate virulence, plant age, and crop residues on seedling blight of sunflower caused by *Alternaria helianthi*. Phytopathology 74:1107-1110.

102. Johnson, G. I. 1985. Occurrence of *Cylindrocladium crotalariae* on peanut (*Arachis hypogaea*) seed. Plant Dis. 69:434-436.

103. Keeling, B. L. 1982. A seedling test for resistance to soybean stem canker caused by *Diaporthe phaseolorum* var. *caulivora*. Phytopathology 72:807-809.

104. Ketring, D. L., and Reid, J. L. 1995. Peanut growth and management. Pages 11-18 *in:* Peanut Health Management. H. A. Melouk and F. M. Shokes, eds. American Phytopathological Society, St. Paul, MN.

105. Kokalis-Burelle, N., and Rodriguez-Kabana, R. 1997. Root-knot nematode. Pages 45-48 *in:* Compendium of Peanut Diseases, 2nd ed. N. Kokalis-Burelle, D. M. Porter, R. Rodriguez-Kabana, D. H. Smith, and P. Subrahmanyam, eds. American Phytopathological Society, St. Paul, MN.

106. Kokalis-Burelle, N., Porter, D. M., Rodriguez-Kabana, R., Smith, D. H., and Subrahmanyam, P. 1997. Compendium of Peanut Diseases, 2nd ed. American Phytopathological Society Press, St. Paul, MN. 94 pp.

107. Krebs, C. J. 1972. Ecology: the experimental analysis of distribution and abundance. Harper and Row, Publishers, Inc., New York. 694 pp.

108. Krigsvold, D. T., and Griffin, G. J. 1975. Quantitative isolation of *Cylindrocladium crotalariae* microsclerotia from naturally infested peanut and soybean soil. Plant Dis. 59:543-546.

109. Krigsvold, D. T., Garren, K. H., and Griffin, G. J. 1977. Importance of peanut field cultivation and soybean cropping in the spread of *Cylindrocladium crotalariae* within and among peanut fields. Plant Dis. Reptr. 61:495-499.

110. Krigsvold, D. T., Griffin, G. J., and Hale, M. G. 1982. Microsclerotial germination of *Cylindrocladium crotalariae* in the rhizospheres of susceptible and resistant peanut plants. Phytopathology 72:859-864.

111. Kucharek, T. A. 1995. Pesticide application techniques for peanut health management. Pages 93-106 *in:* Peanut Health Management. H. A. Melouk and F. M. Shokes, eds. American Phytopathological Society, St. Paul, MN.

112. Kucharek, T. A., and Cullen, R. E. 1989. Control of diseases caused by *Rhizoctonia solani* and *Sclerotium rolfsii* in soybeans beans, peanuts, and cucumbers with flutolanil. Soil and Crop Science Society of Florida, Proceedings 48:31-34.

113. Kucharek, T. A., and Edmonson, G. R. 1990. Suppression of southern stem rot of peanut caused by *Sclerotium rolfsii* with the insecticide chlorpyrifos (Lorsban 15G). Soil and Crop Science Society of Florida, Proceedings 50:41-43.

114. Kucharek, T. A., and Shokes, F. M. 1996. Disease control program for peanuts. Plant Protection Pointers, Extension Plant Pathology Report No. 12, Revision No. 16. Gainesville, FL.

115. Kuthubutheen, A. J. 1984. Effect of pesticides on the seed-borne fungi and fungal succession on rice in Malaysia. J. Stored Prod. Res. 20:31-39.

116. Lewis, P. I., and Filonow, A. B. 1989. Reaction of peanut cultivars to pod rot and their influence on *Pythium* populations in soil. Phytopathology (Abstr.) 79:374.

117. Lockwood, J. L. 1988. Evolution of concepts associated with soilborne plant pathogens. Pages 93-121 *in*: Ann. Rev. Phytopathol. 26: 93-121.

118. Maiti S., and Sen, C. 1988. Effect of moisture and temperature on the survival of sclerotia of *Sclerotium rolfsii* in soil. J. Phytopathology. 121:175-180.

119. Mao, W., Carroll, R. B., and Whittington, D. P. 1998. Association of *Phoma terrestris, Pythium irregulare,* and *Fusarium acuminatum* in causing red root rot of corn. Plant Dis. 82:337-342.

120. Marois, J. J., and Coleman, P. M. 1995. Ecological succession and biological control in the phyllosphere. Can. J. Botany 73 (Suppl. 1) S76-S82.

121. Marois, J. J., and Mitchell, D. J. 1981. Effects of fungal communities on the pathogenic and saprophytic activities of *Fusarium oxysporum* f.sp. *radicis-lycopersici.* Phytopathology 71:1251-1256.

122. Mehan, V. K., and McDonald, D. 1997. Charcoal rot. Pages 11-12 *in:* Compendium of Peanut Diseases, 2nd ed. N. Kokalis-Burelle, D.M. Porter, R. Rodriguez-Kabana, D.H. Smith, and P. Subrahmanyam, eds. American Phytopathological Society, St. Paul, MN.

123. Melouk, H.A., and Damicone, J. P. 1997. Aspergillus crown rot. Pages 7-8 *in:* Compendium of Peanut Diseases, 2nd ed. N. Kokalis-Burelle, D.M. Porter, R. Rodriguez-Kabana, D.H. Smith, and P. Subrahmanyam, eds. American Phytopathological Society, St. Paul, MN.

124. Melouk, H.A., and Backman, P. A. 1995. Management of soilborne fungal pathogens. Pages 75-82 *in:* Peanut Health Management. H.A. Melouk and F.M. Shokes, eds. American Phytopathological Society, St. Paul, MN.

125. Minton, N. A., Csinos, A. S., Lynch, R. E., and Brenneman, T. B. 1991. Effects of two cropping systems and two tillage systems and pesticides on peanut pest management. Peanut Sci. 18:41-46.

126. Mueller, J. D., Shortt, B. J., and Sinclair, J. B. 1985. Effects of cropping history, cultivar, and sampling date on the internal fungi of soybean roots. Plant Dis. 69:520-523.

127. Nelin, M. 1999. CBR spreading in the southeast. The Peanut Grower 11:24-25.

128. Norton, D. C. 1958. The association of *Pratylenchus hexincisis* with charcoal rot of sorghum. Phytopathology 48:355-358.

129. Norton, J. M., and Harman, G. E. 1985. Responses of soil microorganisms to volatile exudates from germinating pea seeds. Can. J. Bot. 63:1040-1045.

130. Nutter, F. W., Jr., and Shokes, F. M. 1995. Management of foliar diseases caused by fungi. Pages 65-73 in: Peanut Health Management. H. A. Melouk and F. M. Shokes, eds. American Phytopathological Society, St. Paul, MN.

131. Odum, E. P. 1983. Basic Ecology. Saunders College Publishing, Philadelphia. 613 pp.

132. Papavizas, G. C. 1985. *Trichoderma* and *Gliocladium*: biology, ecology, and potential for biocontrol. Annu. Rev. Phytopathol. 23:23-54.

133. Papavizas, G. C., and Collins, D. J. 1990. Influence of *Gliocladium virens* on germination and infectivity of sclerotia of *Sclerotium rolfsii*. Phytopathology 80:627-630.

134. Papavizas, G. C., and Lumsden, R. D. 1980. Biological control of soilborne fungal propagules. *in*: Ann. Rev. Phytopathol. 18:389-413.

135. Pegg, G. F., and Jonglaekha, N. 1981. Assessment of colonization of Chrysanthemum grown under different photoperiods and infected with *Verticillium dahliae*. Trans. Br. Mycol. Soc. 76:353-360.

136. Peterson, E. A. 1959. Seed-borne fungi in relation to colonization of roots. Can. J. Microbiol. 5:579-582.

137. Phipps, P. M., and Beute, M. K. 1977. Influence of soil temperature and moisture on the severity of Cylindrocladium black rot in peanut. Phytopathology 67:1104-1107.

138. Phipps, P.M., and Beute, M. K. 1997. Cylindrocladium black rot. Pages 12-15 *in:* Compendium of Peanut Diseases, 2nd ed. N. Kokalis-Burelle, D.M.

Porter, R. Rodriguez-Kabana, D.H. Smith, and P. Subrahmanyam, eds. American Phytopathological Society, St. Paul, MN.

139. Phipps, P. M., and Porter, D. M. 1998. Collar rot of peanut caused by *Lasiodiplodia theobromae*. Plant Dis. 82:1205-1209.

140. Pivonia, S. Cohen, R., Kafkafi, U., Ben Ze'ev, I. S., and Katan, J. 1997. Sudden wilt of melons in southern Israel: fungal agents and relationship with plant development. Plant Dis. 81:1264-1268.

141. Porter, D. M. 1997. Neocosmospora foot rot. Page 23 *in:* Compendium of Peanut Diseases, 2nd ed. N. Kokalis-Burelle, D. M. Porter, R. Rodriguez-Kabana, D. H. Smith, and P. Subrahmanyam, eds. American Phytopathological Society, St. Paul, MN.

142. Porter, D. M. 1997. The peanut plant. Pages 1-2 *in:* Compendium of Peanut Diseases, 2nd ed. N. Kokalis-Burelle, D. M. Porter, R. Rodriguez-Kabana, D. H. Smith, and P. Subrahmanyam, eds. American Phytopathological Society, St. Paul, MN.

143. Porter, D. M., and Phipps, P. M. 1997. Diplodia collar rot. Pages 16-17 *in:* Compendium of Peanut Diseases, 2nd ed. N. Kokalis-Burelle, D. M. Porter, R. Rodriguez-Kabana, D. H. Smith, and P. Subrahmanyam, eds. American Phytopathological Society, St. Paul, MN.

144. Porter, D. M., and Smith, J. C. 1974. Fungal colonization of peanut fruit as related to southern corn rootworm injury. Phytopathology 64:249-251.

145. Porter, D. M., Wright, F. S., and Powell, N. L. 1987. Effects of sprinkler irrigation on peanut diseases in Virginia. Plant Dis. 71:512-515.

146. Reynolds, H. W., and Hanson, R. G. 1957. *Rhizoctonia* disease of cotton in presence or absence of the cotton root-knot nematode. Phytopathology 47:256-261.

147. Rodrigues-Kabana, R., Beute, M. K., and Backman, P. A. 1980. A method for estimating the number of viable sclerotia of *Sclerotium rolfsii* in soil. Phytopathology 70:917-919.

148. Rudolph, R. D., Noegel, K. A., and Rogers, W. D. 1989. Control of diseases of peanut with Folicur (tebuconazole) in the U.S.A. Pflanzenschutz-Nachrichten Bayer 42:187-200.

149. Rupe, J. C., and Gbur, E. E. 1995. Effect of plant age, maturity group, and the environment on disease progress of sudden death syndrome of soybean. Plant Dis. 79:139-43.

150. Sanders, T. H., Blankenship, P. D., Cole, R. J., and Hill, R. A. 1985. Temperature relationships between peanut leaf canopy, stem, and fruit in soil of varying temperatures and moisture. Peanut Sci. 12:86-89.

151. Sanders, T.H. 1995. Harvesting, storage, and quality of peanuts. Pages 23-31 *in:* Peanut Health Management. H.A. Melouk and F.M. Shokes, eds. American Phytopathological Society, St. Paul, MN.

152. Schwartz, H. F., Steadman, J. R., and Coyne, D. D. 1978. Influence of *Phaseolus vulgaris* blossoming characteristics and canopy structure upon reaction to *Sclerotinia sclerotiorum*. Phytopathology 68:465-470.

153. Sharma, N. D. 1974. A previously unreported leafspot of peanut caused by *Phomopsis* sp. Plant Dis. Rptr. 58:640.

154. Shew, B. B., and Beute, M. K. 1984. Effects of crop management on the epidemiology of southern stem rot of peanut. Phytopathology 74:530-535.

155. Shokes, F.M., and Melouk, H. A. 1995. Peanut Health Management in Peanut Production. Pages 1-6 *in:* Peanut Health Management. H.A. Melouk and F.M. Shokes, eds. American Phytopathological Society Press, St. Paul, MN.

156. Sidebottom, J. R., and Beute, M. K. 1989. Control of Cylindrocladium black rot of peanut with cultural practices that modify soil temperature. Plant Dis. 73:672-676.

157. Sidebottom, J. R., and Beute, M. K. 1989. Inducing soil suppression to Cylindrocladium black rot of peanut through crop rotations with soybean. Plant Dis. 73:679-685.

158. Simpson, C.E., and Coffelt, T. A. 1997. Taxonomy of the genus *Arachis*. Pages 2-3 *in:* Compendium of Peanut Diseases, 2nd ed. N. Kokalis-Burelle, D.M. Porter, R. Rodriguez-Kabana, D.H. Smith, and P. Subrahmanyam, eds. American Phytopathological Society, St. Paul, MN.

159. Sivan, A., and Chet, I. 1989. The possible role of competition between *Trichoderma harzianum* and *Fusarium oxysporum* on rhizosphere colonization. Phytopathology 79: 198-203.

160. Smith, D.H. 1997. Alternaria leaf spot. Page 7 *in:* Compendium of Peanut Diseases, 2nd ed. N. Kokalis-Burelle, D.M. Porter, R. Rodriguez-Kabana, D.H. Smith, and P. Subrahmanyam, eds. American Phytopathological Society, St. Paul, MN.

161. Smith, D.H. 1997. Anthracnose. Page 7 *in:* Compendium of Peanut Diseases, 2nd ed. N. Kokalis-Burelle, D.M. Porter, R. Rodriguez-Kabana, D.H. Smith, and P. Subrahmanyam, eds. American Phytopathological Society, St. Paul, MN.

162. Smith, D. H., and Taber, R. A. 1997. Pepper spot and leaf scorch. Pages 24-25 *in:* Compendium of Peanut Diseases, 2nd ed. N. Kokalis-Burelle, D. M. Porter, R. Rodriguez-Kabana, D. H. Smith, and P. Subrahmanyam, eds. American Phytopathological Society, St. Paul, MN.

163. Smith, O. D., Boswell, T. E., Grichar, W. J., and Simpson, C. E. 1989. Reaction of select peanut (*Arachis hypogaea* L.) lines to southern stem rot and Pythium pod rot under varied disease pressure. Peanut Sci. 16:9-14.

164. Smith, O. D., and Simpson, C. E. 1995. Selection of peanut cultivars. Pages 19-22 *in*: Peanut Health Management. H. A. Melouk and F. M. Shokes, eds. American Phytopathological Society Press, St. Paul, MN.

165. Stewart, S. D., Bowen, K. L., Mack, T. P., and Edwards, J. H. 1997. Impact of row spacing and planting date on the canopy environment, abundance of lesser cornstalk borer, and other arthropods, and incidence of aflatoxigenic fungi in peanuts. Peanut Sci. 24:52-59.

166. Subbarao, K. V., and Michailides. 1995. Effects of temperature on isolates of *Fusarium moniliforme* causing fig endosepsis and *Aspergillus niger* causing smut. Phytopathology 85:662-668.

167. Sumner, D. R. 1992. Sterile white basidiomycete. Pages 91-92 *in*: Methods for Research in Soilborne Phytopathogenic Fungi. L. L. Singleton, J. D. Mihail, and C. M. Rush, eds. American Phytopathological Society, St. Paul, MN.

168. Suparyono, and Pataky, J. K. 1989. Influence of host resistance and growth stage at the time of inoculation of Stewart's wilt and Goss's wilt development and sweet corn hybrid yield. Plant Dis. 73: 339-345.

169. Swanson, T. A., and Van Gungy, S. D. 1985. Influences of temperature and plant age on differentiation of races of *Fusarium oxysporum* f.sp. *tracheiphilum* on cowpea. Plant Dis. 69:779-781.

170. Taber, R.A. 1997. Choanephora leaf spot. Page 12 *in:* Compendium of Peanut Diseases, 2nd ed. N. Kokalis-Burelle, D.M. Porter, R. Rodriguez-Kabana, D.H. Smith, and P. Subrahmanyam, eds. American Phytopathological Society, St. Paul, MN.

171. Taber, R. A., and Smith, D. H. 1997. Pestalotiopsis leafspot. Page 26 *in:* Compendium of Peanut Diseases, 2nd ed. N. Kokalis-Burelle, D. M. Porter, R. Rodriguez-Kabana, D. H. Smith, and P. Subrahmanyam, eds. American Phytopathological Society, St. Paul, MN.

172. Taber, R. A., and Smith, D. H. 1997. Phomopsis leaf blight. Page 26 *in:* Compendium of Peanut Diseases, 2nd ed. N. Kokalis-Burelle, D. M. Porter, R. Rodriguez-Kabana, D. H. Smith, and P. Subrahmanyam, eds. American Phytopathological Society, St. Paul, MN.

173. Taylor, D. P., and Wyllie, T. D. 1959. Interrelationship of root-knot nematodes and *Rhizoctonia solani* on soybean emergence. (Abstr.) Phytopathology 49:552.

174. Teare, I. D., Shokes, F. M., Gorbet, D. W., and Littrell, R. H. 1984. Peanut growth responses to different levels of leafspot. Agronomy Journal. 76:103-106.

175. Tomimatsu, G. S., and Griffin, G. J. 1988. Infection levels and extent of colonization by *Cylindrocladium crotalariae* of roots of Cylindrocladium black rot-susceptible and –resistant peanut cultivars in naturally infested soil. Canadian Journal of Plant Pathology 10:11-14.

176. Trapero-Casas, A., and Kaiser, W. J. 1992. Influence of temperature, wetness period, plant age, and inoculum concentration on infection and development of Ascochyta blight of chickpea. Phytopathology 82:589-596.

177. Trapero-Casas, A., Kaiser, W. J., and Ingram, D. M. 1990. Control of Pythium seed rot and preemergence damping-off of chickpea in the U. S. Northwest and Spain. Plant Dis. 74:563-569.

178. Tylka, G. L., and Hunter, B. B. 1985. Quantitative recovery of *Cylindrocladium scoparium* from nursery soils in Pennsylvania. (Abstr.) Phytopathology 75:629.

179. Vanderplank, J. E. 1963. Plant Diseases: Epidemics and Control. Academic Press, New York. 349.

180. Wadsworth, D. F., and Melouk, H. A. 1985. Potential for transmission and spread of *Sclerotinia minor* by infected peanut seed and debris. Plant Dis. 69:379-381.

181. Waliyar, F. 1986. Etude comparative de l'evolution de la mycoflore rhizospherique de deux varietes d'arachide (*Arachis hypoqaea* L.) au Senegal. Oleagineux 41:129-139.

182. Wells, H. D., Bell, D. K., and Jaworski, C. A. 1972. Efficacy of *Trichoderma harzianum* as a biocontrol for *Sclerotium rolfsii.* Phytopathology 62:442-447.

183. Whitty, E. B., Gorbet, D. W., and Dunavin, L. S., Jr. 1999. Peanut Varieties for 1999. Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. http://edis.ufl.edu/Body_AA199.

184. Wynne, J. C., and Coffelt, T. A. 1982. Genetics of *Arachis hypogaea* L. Pages 50-94 *in:* Peanut Science and Technology. H. E. Pattee and C. T. Young, eds. American Peanut Research and Education Society, Inc., Yoakum, TX.

185. Young, T. R., and T. A. Kucharek. 1977. Succession of fungal communities in roots and stalks of hybrid field corn grown in Florida. Plant Dis. Reptr. 61:76-80.

BIOGRAPHICAL SKETCH

Robert C. Kemerait, Jr. was born on 21 January 1965 in Gainesville, Florida. He graduated from Satellite High School in Satellite Beach, Florida, in 1983. He received a bachelor of science degree in biology from Davidson College, Davidson, North Carolina, in 1987. He received a bachelor of science degree in chemistry from the University of Florida in 1989.

While working as an analytical chemist in Gainesville, he decided to pursue a career that would allow him to spend more time working outdoors with plants and being of service to others. He began post-baccalaureate work in the Botany Department at the University of Florida in 1993 and entered the Plant Pathology Department for graduate studies in August of 1994.

In June of 1997 Mr. Kemerait married Pamela Jean Santiago Lopez, who received her doctorate in horticulture at the University of Florida in 1998. Their daughter, Mia Perrine Lopez Kemerait, was born in May of 1999. Mr. Kemerait has accepted a position as an assistant professor in plant pathology at the University of Georgia. He will be the extension pathologist for peanut and cotton and will live and work in Tifton, Georgia, where he hopes to find time to pursue his life-long passion of hunting for Indian arrowheads.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Thomas A. Kucharek, Chair
Professor of Plant Pathology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Richard D. Berger
Professor of Plant Pathology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

David J. Mitchell
Professor of Plant Pathology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Elmo B. Whitty
Professor of Agronomy

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Lance G. Peterson
Advisor, Coastal U. S.
Technological Development
DowAgroSciences

This dissertation was submitted to the Graduate Faculty of the College of Agricultural and Life Sciences and to the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

May 2000

Dean, College of Agricultural and Life Sciences

Dean, Graduate School